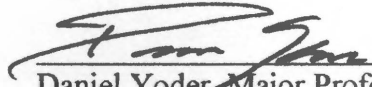
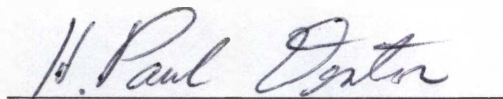


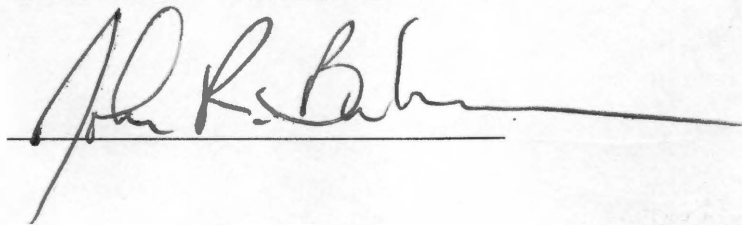
To the Graduate Council:

I am submitting herewith a thesis written by Meredith L. Crosby entitled "Development of an Experimental Technique for Simulating Sheet and Rill Erosion Using Multiple Box Plots and a Rainfall Simulator." I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

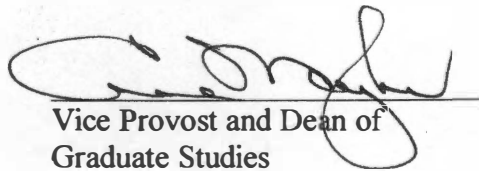

Daniel Yoder, Major Professor

We have read this thesis and
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Vice Provost and Dean of
Graduate Studies

**DEVELOPMENT OF AN EXPERIMENTAL TECHNIQUE FOR
SIMULATING SHEET AND RILL EROSION USING
MULTIPLE BOX PLOTS AND A RAINFALL SIMULATOR**

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Meredith Leigh Crosby
August 2002

Thesis

2002

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DEDICATION

This thesis is dedicated to my parents, William L. Crosby and Mary Linda Crosby,
for setting examples that I hope to one day live up to, and to my siblings,
Leslie, Audra, and Will Crosby, for their love and support.

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There were several other individuals that provided skills and labor in carrying out this project. Thanks to Adam Daugherty, Trey Cavin, Walker Garner, Will Pinson, Matt Rice, and Craig Wagoner.

ABSTRACT

Scientists must discover new methods to control erosion. Laboratory-scale box plots offer a way to test and compare these methods rapidly and with repeatability, but only for interrill or sheet erosion. Current box plot designs do not provide sufficient slope length for studying combined sheet and rill erosion on steep slopes. Constructing a single long box plot for this purpose is extremely difficult and impractical.

The purpose of this research was to develop a method for studying sheet and rill erosion on long, steep slopes in a laboratory setting by using multiple box plots and a rainfall simulator. Devices were designed to collect runoff from the bottom of an erosion box, to transport the runoff and associated sediment to the top of another box, and to redistribute the runoff at the top of the second box in a fashion to simulate runoff conditions at the bottom of the first box. This simulates the effects of a slope twice the length of one box. Observations were made of the box plots and of a site where natural rainfall occurred on a continuous slope. These sites were compared visually to evaluate the ability of the sequential box plots to simulate conditions found on a single long slope in the field.

Based on these observations, the experimental system simulates combined sheet and rill erosion conditions very well. Channels of runoff were continued from one box to the next. Rills began forming in the lower third of the first box, and there was rill development throughout the second box. Visually, rill development in the boxes was similar to rill development on a slope of equal length in the field.

Recommendations for improving the experimental design were made, as were recommendations for future research.

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CHAPTER 1

INTRODUCTION

Background

Erosion control is a problem in many areas of the world, both in rural and in urban settings. The detrimental effects of erosion are not limited to the site where it occurs. The off-site effects of stream degradation and nonpoint source pollution can cause problems miles away from the eroding site. In agricultural areas, the loss of soil leads to decreased productivity of the land and many other problems. In urban areas, the loss of topsoil is not just aesthetically unpleasing. Moderate to severe erosion can create serious construction problems in addition to the off-site concerns. While interrill erosion leads to a large amount of soil loss, it is not the only type of erosion. As the volume of runoff increases with longer slopes, channels begin to form. Small channels caused by the soil microtopography result in rill erosion.

The focus of this project is development of a method for studying combined sheet and rill erosion, which is of particular concern on long, steep slopes. Rill erosion occurs when surface water flow is concentrated with enough depth and slope to cause incision into the soil (Ellison and Ellison, 1947; Haan et al., 1994; Meyer and Ports, 1976; Meyer et al., 1975). Rills are shallow channels (Foster, 1982; Merz and Bryan, 1993; Nearing et al., 1997) that are initially parallel, but form networks over time (Haan et al., 1994). The formation of rills is related to slope steepness and length. Long slopes are necessary to generate the volume of runoff needed for rill formation, and slope steepness contributes to the velocity of flow required for rill incision (Haan et al., 1994). Since rill erosion requires enough slope length to concentrate runoff, there is a minimum slope length

needed for rill erosion research. Projections of this length vary from 3 meters (9.8 ft) to 10 meters (33 ft) (Lal and Elliot, 1994; Liu et al., 1994; Nearing et al., 1999; Renard et al., 1997). Controlling rill erosion is often an issue on construction sites, where slopes can be many meters long, and can have steepnesses of 50% or greater. For both economic and environmental reasons, conservationists must find methods of controlling the problem of rill erosion on construction sites and other long, steep slopes.

When a new method for erosion control is devised, it must be tested to determine its effectiveness. These tests can be performed in the field or in the laboratory. While there are several benefits to field tests for erosion, there are also several problems. Field tests are not as repeatable as tests conducted in the laboratory. In the field, factors such as rainfall and soil moisture cannot be easily controlled. Water erosion tests must be performed during and after rainfall events. Field sites can be difficult or impossible to reach during the times when access is most needed. Another concern with field testing is the limited number of tests that can be performed on a particular site. Once a field plot has eroded to certain point, it cannot be used again. Another plot must be found for subsequent testing.

The problems of control and access that occur in the field do not occur in the laboratory. One method of laboratory testing is using a rainfall simulator and box plots. A box plot is a box of soil that has been constructed to create a uniform, small scale plot. These boxes can be manipulated more easily than field plots. Using a rainfall simulator with box plots allows for control of rainfall rate and slope, and it provides a more uniform testing environment. This allows the researcher to focus on the factor being

tested. Also, box plots can be repacked with soil when necessary. This allows the researcher to repeat tests much more easily than in the field.

Rainfall simulators and box plots have been widely used for studying interrill erosion. It is more difficult to study combined sheet and rill erosion using box plots. Rill development requires the formation of channels in the soil, which is strongly related to slope length and steepness. Long steep slopes are very difficult to construct in the laboratory. A 50% slope 30 meters (98 ft) long would be nearly 13.5 meters (44.3 ft) tall. If this box was only 1 meter (3.3 ft) wide and 0.15 meter (0.5 ft) deep, it would take up nearly 27 square meters (950 square feet) of horizontal surface area and weigh several tons. This is not feasible for construction under a rainfall simulator.

The method that most researchers have used to combat the lack of a long slope is to add water to the top of a shorter slope (Alberts et al., 1980; Franti et al., 1996; Govers, 1991; Huang et al., 1999; Meyer et al., 1972; Walker et al., 1977), but there are drawbacks to this method. One issue is that most researchers used clean water for the inflow. Runoff from an upslope area could clearly contain substantial sediment. Water containing sediment is less erosive than clean water traveling at the same velocity, due to the current sediment load absorbing much of the transport capacity (Ellison and Ellison, 1947; Foster, 1982; Foster et al., 1982b; Haan et al., 1994; Lal and Elliot, 1994; Nearing et al., 1997). A second issue is that when inflow is added it is usually spread evenly across the entire box plot width. Rill erosion occurs from flow in small channels. In order to accurately simulate upland erosion conditions, flow added to the top of a box plot would need to be concentrated in the same way and volumes that it would in the field. A third issue is that when inflow is added to a short slope, the researcher can only

study the lowest section of the larger slope. In many cases it would be beneficial to look at the entire slope length.

This project attempts to solve these problems by dividing a single slope into shorter segments. The runoff from the end of one segment is collected and added to the top of the next segment while maintaining the distribution of runoff and sediment load across the width from one box to the next.

Objectives

The main objective of this research is to develop a technique for simulating sheet and rill erosion on longer slopes in a laboratory environment using multiple connected box plots under a rainfall simulator. Achieving this objective requires collecting the runoff from one box, delivering it to the top of the next box, and reapplying it in a condition as near as possible to the conditions under which it left the previous box. This process can be broken down into three sections: runoff collection, runoff delivery, and runoff redistribution. Each of these sections has specific criteria to be met.

There are three criteria that need to be met with the design of the runoff collection system:

1. It must divide the runoff area into many small sections, whose widths are no wider than the width of a typical rill. This will maintain the actual distribution of water across the box width.
2. It must be designed to allow collection to occur without ponding of the runoff, which would allow the transported sediment to settle.
3. It should minimize any opportunity for the sediment to settle out of the water.

The runoff delivery system design must meet the following five criteria:

1. It must be able to transport the runoff water and associated sediment in segments from the bottom of the box plot frame to the top of the next box without allowing the sediment to settle.
2. It must have the capability to handle many channels coming from the collection device.
3. It must be able to function with some of the channels filled to capacity and some of the channels empty at the same time.
4. It must be able to handle all the runoff volume from the box in a single channel.
5. It must be relatively inexpensive.

The design's runoff redistribution system needs to fulfill three criteria:

1. It must apply the water to the second box at approximately the same velocity it had at the bottom of the first box.
2. It must apply the water to the second box at the same location in the width as it was removed from the first box.
3. It must prevent the sediment from settling when the transportation energy is removed.

Meeting the criteria for each of the three areas will create conditions that allow the main objective to be met. Visual observation of the box plots during and after testing will determine if the objective has been met. Rills simulated in the testing should be realistic representations of those that occur in the field. Just as there are criteria for design, there are criteria for success:

1. Channels should begin forming by the end of the first box.
2. Channels forming in one box should begin at the same location in the next box.
3. Channels should be shallow.
4. Channels should be narrow.
5. Channels, once formed, should migrate upward through headcut erosion.
6. Channels should cut down into soil, then widen if a less erodible layer is met.
7. Channels should be initially parallel, then possibly form a network over time.

It is extremely difficult to quantify a rill. The characteristics described in the criteria for success define rill erosion, but the exact depth and width of a rill depends on a variety of soil and rainfall characteristics. In the same manner the location on the slope where rill formation begins depends on the soil, the slope, and the amount of rainfall. Since exact measurements of rills vary, visual observations will be made to determine if the channels in the box plots meet the generalized criteria defining rill erosion. If these criteria are met, then the design has achieved the overall objective of simulating sheet and rill erosion using box plots and a rainfall simulator.

CHAPTER 2

REVIEW OF LITERATURE

Rill Erosion

In order to determine if the designed system accurately simulates rill erosion, it is important to define rill erosion. For rill erosion to occur, runoff must be concentrated into small channels (Ellison and Ellison, 1947; Foster, 1982; Haan et al., 1994; Meyer and Ports, 1976; Meyer et al., 1975). Rills are randomly located on the slope (Haan et al., 1994), and erosion in rills is not uniform (Foster and Meyer, 1977). Rill erosion occurs when shear stress created by the flow of runoff overcomes the forces holding the soil in place (Foster, 1982; Foster and Meyer, 1977; Haan et al., 1994). The shear stress depends on the slope and the depth of the flow (Haan et al., 1994; Meyer and Ports, 1976; Shainberg et al., 1992) because the velocity of flow increases with increasing slope steepness (Foster et al., 1984).

While the shear stress acts to remove soil from the channels, there are also forces holding the soil in place, and helping it resist shear stresses. Haan et al. (1994) lists many of these factors, including soil shear strength, soil salinity, moisture content, percentage clay, mean particle size, dispersion ratio, vane shear strength, organic matter content, cation exchange capacity, calcium-sodium ratio, and plasticity. The interaction between the shear stress and the forces holding the soil determines the rill detachment potential. This detachment potential, along with the transport capacity of the water and the sediment load, controls the development and growth of rills (Haan et al., 1994).

The runoff transport capacity or sediment transport capacity is important because erosion can be limited by this ability of the water to transport sediment (Ellison and

Ellison, 1947). The amount of soil detached in a rill is equal to the potential detachment when the sediment load equals zero, and no detachment occurs when the sediment load equals the transport capacity (Haan et al., 1994). The runoff transport capacity increases with increased slope because the flow velocity increases with increased slope (Foster et al., 1984). The sediment load within the rill comes not only from rill erosion, but also from the interrill erosion delivered to the rill (Foster, 1982; Haan et al., 1994; Meyer et al., 1975). This means that rill erosion is dependent on what occurs in the interrill area (Foster, 1982). This will be discussed further below.

The interaction of runoff factors and soil factors present in rill erosion means that rill characteristics vary not only between soils and plots, but also between rainfall events. Despite this variety, there are some factors that are characteristic of rills. The most basic characteristics of rill erosion are that soil is detached by water flowing in small channels, that the channel positions are controlled by small irregularities in the soil surface (Ellison and Ellison, 1947), and that for channels to form there must be an accumulation of runoff from upslope (Foster, 1982). This means that there is a minimum slope length required for rill development on a given soil at a given slope.

Once channels have formed, rills develop initially by the upward migration of headcuts within the channels (Foster, 1982; Haan et al., 1994; Meyer et al., 1975). In addition to the headcut erosion, the sidewalls of rills are undercut by the flow and then wash away (Foster and Meyer, 1977; Haan et al., 1994; Meyer et al., 1975).

When rills first form they are narrow. The channels cut downward into the soil until they reach a layer that is less erodible, then they widen (Foster, 1982; Foster and

Meyer, 1977). In addition to being narrow, rills are initially roughly parallel. As the runoff rate increases the runoff overtops the edges of the rill, and rill networks form (Haan et al., 1994).

Rainfall Simulators

Rainfall simulators have been widely used for both field and laboratory studies, including studies of soil cover, crop residue, and management practices, as well as studies concerning slope length and steepness and erosion mechanics. According to Meyer (1994), rainfall simulators are more rapid, more efficient, more controlled, and more adaptable than natural rainfall.

While there are advantages to using simulated rainfall, there are also limitations. One of these limitations is the difficulty in simulating natural rainfall conditions. Meyer (1994) lists several characteristics that should be met in designing a rainfall simulator. These include a drop size distribution that is near that of natural rainfall, rainfall intensities that are in the range of the storm of interest, a research area that is relatively large, capability of repetition, and portability.

Researchers have found a variety of ways to create simulated rainfall meeting those requirements. Most studies have used a nozzle-type rainfall simulator (Alberts et al., 1980; Foster et al., 1982a; Meyer et al., 1972; Meyer et al., 1970; Shelton et al., 1985). These allow for a wide variety of drop sizes (Meyer, 1994). Laws and Parsons (1943) found that drop sizes in natural rainfall ranged from 0.25 mm (0.01 in.) to 6.25 mm (0.25 in.) in diameter, with a median diameter by volume of 2.7 mm (0.11 in.).

Nozzle selection is not the only factor important in selecting a rainfall simulator design. Nozzle height and spacing must also be considered. With a Fulljet HH30WSQ at 34.5 kPa (5 psi), nozzle heights of at least 2.44 m (8 ft) allow the drops to reach terminal velocity before they reach the surface (Shelton et al., 1985). Buchanan (2000) used a Fulljet HH30WSQ at 34.5 kPa (5 psi) set to this height on a 2.4-m (8-ft) on-center nozzle spacing to achieve a 64 mm/hr (2.5 in./hr) rainfall, which is a very common simulated intensity (Alberts et al., 1980; Foster et al., 1982a; Meyer et al., 1972; Meyer et al., 1970).

Once a rainfall simulator design has been selected, the duration and timing of the tests must be determined. Most researchers using simulated rainfall conducted tests under a variety of soil moisture conditions (Alberts et al., 1980; Foster et al., 1982a; Meyer et al., 1975; Meyer et al., 1972; Meyer et al., 1970). The most common method was to run the simulator for 60 minutes on dry soil, then to perform two 30-minute tests 24 hours later. These 30-minute runs are generally separated by 15 minutes (Meyer et al., 1972; Meyer et al., 1970). This shows the effect of the rainfall on dry soil, wet soil, and very wet soil.

Rainfall simulators that are designed for small field plots and laboratory studies only cover a small area. These simulators are suitable for evaluations of interrill erosion (Meyer, 1994). To study rill erosion, rainfall must be applied to areas large enough for runoff to accumulate (Meyer, 1994). Meyer (1994) suggests that testing of slopes longer than the rainfall simulator can manage may be accomplished by adding inflow water. This will be discussed later.

Box Plots

A common laboratory erosion research method is to combine simulated rainfall with a box plot, which is simply a box that contains soil. Many researchers have utilized these boxes as the foundation for their research (Franti et al., 1996; Gabbard et al., 1998; Govers, 1991; Huang et al., 1999; Merz and Bryan, 1993; Schmidt, 1991; Walker et al., 1977). One advantage of box plots is that they can easily be manipulated. Box plots allow the researcher to control a variety of factors much more easily than they can be controlled with larger plots (Mutchler et al., 1994), such as soil moisture. Gabbard et al. (1998) and Huang et al. (1999) used ports in the boxes to obtain a variety of moisture conditions through drainage and hydration. In the study by Gabbard et al. (1998) this moisture manipulation, along with the addition of inflow and adjustment of slope, was used to model segments of slopes at different landscape positions.

Other research was performed with box plots that could be set to a variety of slopes. Buchanan (2000) used 30, 40, and 50 percent slopes for his tests, while Walker et al. (1977) could set the slope anywhere up to 32 percent. The box plot design used by Huang et al. (1999) could be adjusted to slopes between 0 and 40 percent at 5 percent increments. This flexibility is one of the main advantages of box plots.

Another advantage of box plots is that they allow for rapid testing. Soil can be repacked into boxes. This also allows for more repeatable testing. Different treatments can be tried quickly under the same conditions, or the same treatment can be replicated much more efficiently than in the field.

While box plots have advantages, there are also disadvantages. One major disadvantage is that edge effects can play more of a role in small plots than in large plots

(Mutchler et al., 1994). These edge effects are caused by soil or water that should be in the plot splashing out of the plot area, soil or water that should not be in the plot area splashing into the plot, and effects of barriers to flow created by the plot boundaries. One way to minimize edge effects from splash is to delineate the plot with metal strips (Meyer, 1994; Mutchler et al., 1994). This ensures that rainfall striking the plot surface stays on the plot area, and that rainfall near the plot area is diverted. The problem of flow barriers still exists.

Another disadvantage of box plots and other small plots is that they simply are not large enough to study rill erosion. The exact plot size needed to simulate rill erosion is not defined. Lal and Elliot (1994) suggest a minimum length of 3 m (9.8 ft) for rill erosion tests. Renard et al. (1997) assumed that rill erosion is not significant for slope lengths less than 4.6 m (15 ft). Mutchler et al. (1994) suggest a minimum length of 5 m (16 ft) for rill erosion tests, but recommend 10 m (33 ft) as a better length.

Only one study was found using a length of 10 m (33 ft) in a laboratory setting, and this design had a fixed slope of 8 percent (Merz and Bryan, 1993). Other than that study and research by Franti et al. (1996) using a fixed slope 5.5 m (18 ft) in length, all research found using box plots was performed using lengths between 3 m (9.8 ft) and 5 m (16 ft) (Gabbard et al., 1998; Govers, 1991; Huang et al., 1999; Walker et al., 1977). When researchers use box plots to simulate a longer slope, inflow is added to the top of the slope (Franti et al., 1996; Gabbard et al., 1998; Huang et al., 1999).

Adding Inflow

The maximum slope length found in the literature for artificial slopes created in the laboratory was 10 m (33 ft) (Merz and Bryan, 1993). Most researchers attempted to overcome the limited slope length by adding water to the top of the slope. The amount of water added was dependent on the amount of runoff needed for that particular test. Franti et al. (1996) performed tests to simulate the effects of incorporated residue on a rill by using inflow water rates ranging from 0.10 L/sec (1.6 gal/min) to 0.43 L/sec (6.8 gal/min). Walker et al. (1977) used a rate of 0.07 L/sec (1.1 gal/min) when testing an experimental setup for erosion studies. Nearing et al. (1997) used five flow rates ranging from 132 L/sec (0.6 gal/min) to 1056 L/min (4.7 gal/min) for their test on the hydraulics of eroding rills. In Govers' (1991) research, inflow rates ranged between 0.12 L/sec (1.9 gal/min) and 0.15 L/sec (2.4 gal/min).

The addition of inflow to the top of the slope is not a phenomenon exclusive to laboratory studies. Alberts et al. (1980) performed a field study where water was added to the top of a plot at rates from 0.07 L/sec (1.1 gal/min) to 1 L/sec (16 gal/min). Meyer et al. (1972) studied critical slope length for mulch failure by adding water to the top of a 10.67-m (35-ft) slope at rates that were equal to, twice, and triple the amount of runoff expected from the plot under a 63.5 mm/hr (2.5 in/hr) rainstorm. This wide variety of inflow amounts simply shows the variety of conditions that are studied in erosion research.

The methods for applying the water are as varied as the rates used. Most researchers used clean water for the inflow (Alberts et al., 1980; Foster, 1982a; Franti et al., 1996; Govers, 1991; Meyer et al., 1975; Meyer et al., 1972; Nearing et al., 1997;

Walker, et al., 1977). Much of the literature did not describe in detail how the water was applied, but a few studies did. Franti et al. (1996) passed tap water under pressure through layers of plastic mesh and gravel, and over a 60-cm (24-in.) smooth transition section into the soil bed. The system designed by Walker et al. (1977) passed water through a series of baffles and into a stilling bay.

The stilling bay concept (Walker et al., 1977) and gravel layers (Franti et al., 1996) solved one of the problems with adding inflow by removing the water's excess energy. Another problem is that clean water is more erosive than water containing a sediment load. Water traveling at a given velocity can only carry a set amount of sediment, so clean water will have more available transport capacity and thus greater erosion potential than would water reaching that point in the slope after having traveled over a substantial length of soil. One method to solve this problem is to pass the inflow over a sacrificial soil area to reduce the erosivity. Franti et al. (1996) dealt with excessive scouring at the top of the box by burying gravel just under the soil surface. The gravel absorbed the excess energy as it was exposed by the eroding soil.

The simplest way to solve the problems created by using clean water is to use water that contains sediment. Guy et al. (1987) performed a study of transport capacity using a complicated method for injecting soil into the flow. Only one other study was found that used water containing sediment. Huang et al. (1999) used a dual box setup where a "feeder" box was connected to the test box. The slope steepness and rainfall intensity level for the "feeder" box was maintained separately from the main box. The "feeder" box was manipulated to give low and high sediment levels for the water running into the test box. This study is interesting because it used actual runoff water from an

upslope location as the inflow. Adding runoff from an upslope location is beneficial because runoff from upslope is what is actually flowing over a downslope location. While this study used runoff from an upslope location, there was no description of how the runoff was distributed. If the runoff is evenly distributed across the slope width, it would not accurately model what would be occurring in the lower portion of a long, steep hillside. Runoff begins to form channels as it flows downslope.

Combining Inflow and Rainfall

While the addition of inflow was a common factor in laboratory studies of rill erosion, not all researchers used inflow and rainfall at the same time. Nearing et al. (1997) simply added flow across a preformed rill with no rainfall. In the study by Franti et al. (1996), artificial rainfall was applied before the test to create near saturated conditions, but not during the test.

The combination of rainfall and overland flow is important because that is what actually occurs in the field. While erosion in interrill areas is independent of what happens in rills, erosion in the rills depends on the inputs from the interrill area (Foster, 1982). Since interrill erosion occurs from raindrop impact (Haan et al., 1994), it is important to have rainfall over the area.

While not all researchers who added inflow also used rainfall, most did (Alberts et al., 1980; Govers, 1991; Huang et al., 1999; Meyer, 1972; Walker et al., 1977). Even with a combination of inflow and rainfall, these studies only consider the lowest portion of a large slope.

No research was found where a long, steep slope was studied in its entirety in the laboratory. Most box plots studies focus on interrill erosion due to size limitations. Rill erosion research performed in the laboratory is generally conducted by adding inflow to the top of a slope. Usually this inflow is clean water spread uniformly across the slope width. This not only creates a problem due to the transport capacity of clean runoff, but it does not take into account the interrill areas. The input of soil and water from interrill areas has a great impact on what occurs in the rills. It is important to combine sheet and rill erosion when trying to simulate field conditions in the laboratory. This project attempts to design a system that will allow researchers to study both sheet and rill erosion on an entire slope by dividing it into smaller segments.

CHAPTER 3

MATERIALS AND METHODS

The experimental system designed to simulate sheet and rill erosion uses multiple box plots. Runoff is collected from the bottom of the first box and delivered to the top of the second box, where it is redistributed. Figure 1 is a schematic of the system, and Figure 2 on page 19 shows how the runoff collection, delivery and redistribution device fit together. This chapter describes the box plots, rainfall simulator, runoff collection device, runoff delivery system, and runoff redistribution device, as well as the field sites used for comparison.

Box Plots

The box plot design was that used by Buchanan (2000). The 3.4-m (11-ft) long by 1-m (3.3-ft) wide boxes were filled with soil to a depth of 15 cm (0.5 ft). The soil was underlain with a very thin layer of sand covered with a layer of geotextile material. This allowed water to drain through the soil and out openings at the bottom of each box. Sheet-metal guards were placed along the boxes to divert splash down the slope.

The soil used in the boxes was taken from a Sequatchie Silt Loam Ap horizon. The soil was sieved through 1/2 inch (15 cm) mesh upon collection to remove large clods. The soil was then placed directly into the boxes, and was compacted by walking. The boxes were left exposed to allow the soil to go through several wet-dry cycles so that settling could occur.

When the soil had settled for several weeks, additional soil was added to any low areas. All plant material that had sprouted in the boxes was removed. The surface was lightly raked to eliminate any surface crusting. After the soil surface was prepared, the

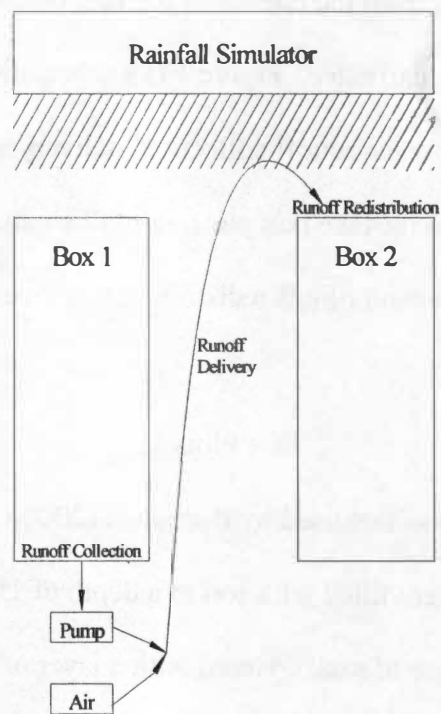


Figure 1. Schematic of system.

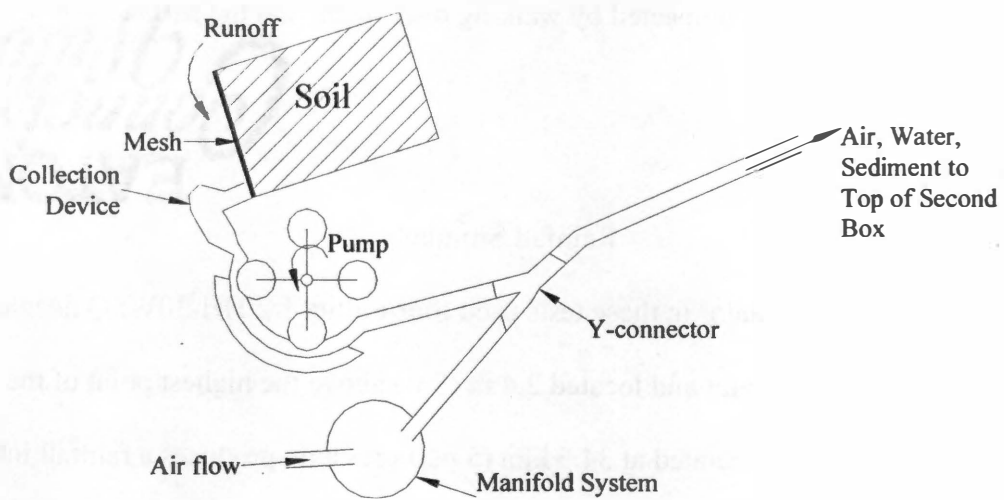


Figure 2. Schematic of air and water flow through collection and delivery system.

boxes were covered with black plastic until testing. The boxes were placed on the variable-slope stand used by Buchanan (2000).

Between the first and second runs of testing, the second box was replaced and the first box was resurfaced. Both the new second box and the first box were tilled with a Ryobi 410r 2-cycle garden cultivator. Any plant matter and debris visible on the surface was removed from the box. Extra soil was added to fill the low places in the surface. The soil boxes were then compacted by walking over them, and the surface was leveled to the edges of the box.

Rainfall Simulator

The rainfall simulator in these tests used four Fulljet 1/2 HH-30WSQ nozzles placed 2.4-m (8 ft) on-center and located 2.4 m (8 ft) above the highest point of the soil. This arrangement when operated at 34.5 kPa (5 psi) pressure, produces a rainfall intensity of 64 mm/hr (2.5 iph). This was the same rainfall from this simulator that was found to be uniformly distributed when used in earlier testing (Buchanan, 2000).

The tests were run at 30-minute intervals with at least fifteen minute breaks for photography and to check and adjust system components. The first set of tests was as follows:

Test 1

Day 1 – Two 30-minute runs with a 10-minute break (Runs 1 and 2)

Day 3- One 30-minute run (Run 3)

Day 4- Two 30-minute runs with a 30-minute break (Runs 4 and 5)

Day 5- One 30-minute run (Run 6)

Day 6- One 30-minute run (Run 7)

The first box was then allowed to air dry before resurfacing for the second set of tests.

The second set of testing was conducted in the following intervals:

Test 2

Day 1- One 45-minute run in the morning, One 30-minute run in the afternoon
(Runs 1 and 2)

Day 2- Three 30-minute runs (one morning and two afternoon with a 15-minute
break) (Runs 3, 4, and 5)

Day 3- Two long runs for demonstration, taping, and photography (Demonstration
Run and Final Run)

The boxes were covered between days of testing to prevent loss of soil if a natural rainfall event occurred.

Runoff Collection Device

The collection device was designed to divide the runoff so that the flow from each 25-mm (1-in.) wide segment of the slope would be collected separately. This divided the width of the box plot into 39 segments. A piece of # 3 size wire mesh was cut to a size just larger than the end of the box. This mesh was placed between the collection device and the soil to hold the soil in place in the box. The # 3 size, which has openings of 8 mm (0.32 in.), was selected during preliminary testing because it held the soil in place without causing ponding of the water. During this testing, the silt loam used fell through larger-sized mesh, and clogged a smaller-sized mesh with sediment.

Schedule 40 IPS PVC elbows with female threading (FIPT) on one end were cut as shown in Figure A-1. These fittings were riveted to a piece of sheet-metal bent as shown by Figure A-2. Any open spaces between the PVC fittings or between the fittings and the sheet metal were sealed with silicone. Figure 2 on page 19 shows how the screen and collection device align with the soil box, and Figure 3 on page 23 shows the collection device and the tubing that connects it to the pump.

Runoff Delivery System

Once the runoff was collected from the first box it had to be delivered to the top of the second box. The runoff delivery system was used for this purpose. Air flow was used to transport the water, because it moved the water quickly and minimized the mass of sediment trapped in the lines. Flow meter measurements of the minimum air flow per line required for transportation showed that an air compressor providing almost 2.3 m³/min (80 ft³/min) was needed to deliver the water and sediment to the top of the second box.

A manifold system was used to divide the air flow. The air was divided from one line to four lines using a manifold as shown in Figure A-3. Air flowed from each of the four outflow lines through a piece of 9.6 mm (0.38 in.) tubing into a second manifold. Three of these manifolds had 10 outlets, while the fourth had 9 outlets. An example of these manifolds is shown in Figure A-4. From each outlet of these manifolds the air flowed through a piece of copper tubing with a 1.6 mm (0.17 in.) opening. This orifice, shown in Figure A-5, was manufactured to create significant head loss, ensuring even air flow from all of the openings of the manifold. All tubing was 9.6-mm (0.38-in.) ID

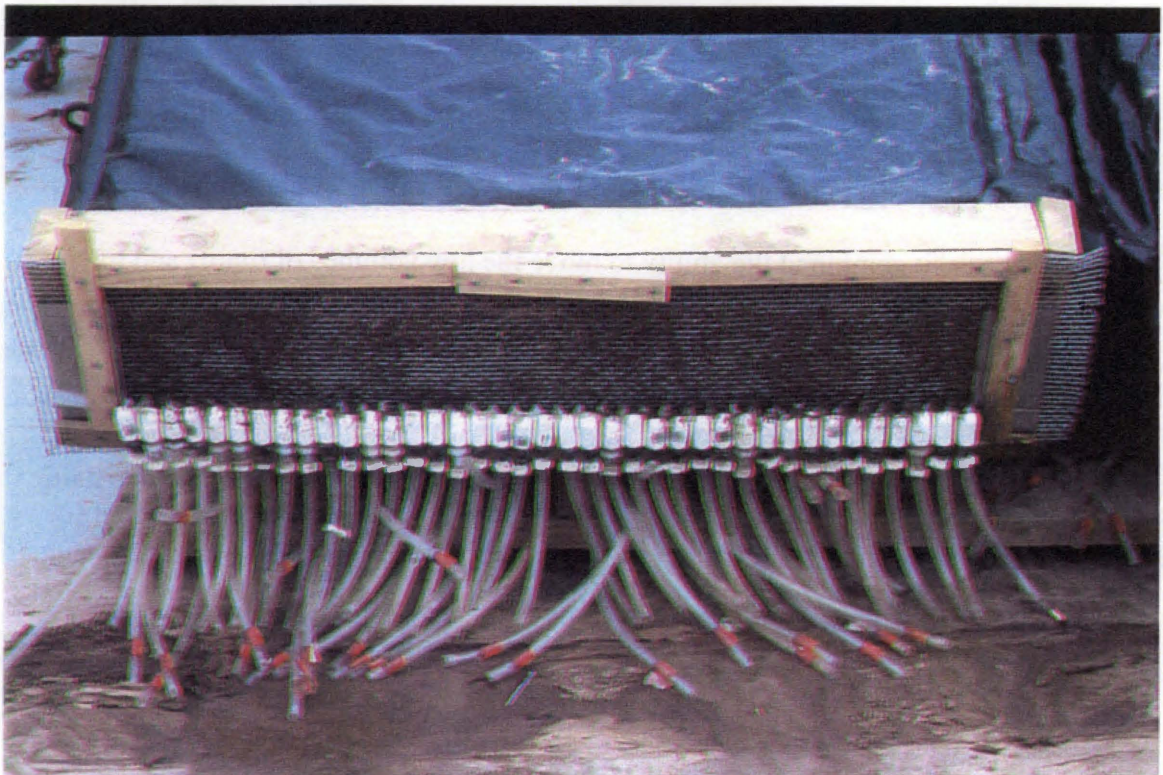


Figure 3. Runoff collection device and tubing.

Tygon, which with the design air flow provided delivery tube air velocities of over 12 m/s (40 ft/s). This was the minimum velocity needed to transport the water and sediment to the top of the second box. The tubing size was selected during preliminary testing because it was the minimum tubing size large enough to transport the largest particles that could pass through the screen into the collection device. The tubing was kept at the minimum diameter because the amount of air flow needed to transport the runoff increases with the square of the diameter of the tubing.

The runoff/sediment mixture entered a y-connector after passing through the collection device and a peristaltic pump used as a check valve. A peristaltic pump was selected because it combined the ability to move the low volumes of runoff and to transport water containing sediment, while providing an air seal to keep the pressurized air in the delivery system from escaping through the collection device. Runoff flowed from the collection device tubing to a hose barb coupling connecting it to the peristaltic pump. Figure 2 on page 19 illustrates the direction of water and air flow in the system.

Design of Peristaltic Pump

Silicone tubing with 9.6-mm (0.38-in.) inside diameter was used in the pump. Two 64-cm (25-in.) long pieces of 6-inch diameter Schedule 40 IPS PVC pipe were cut and supported with a 1-inch angle iron frame. This served as the plate to compress the tubing. A drawing of this portion of the device is shown in Figure A-6.

Eight (four for each half) 41-cm (16-in.) long, 4.8-cm (1-7/8-in.) diameter conveyor rollers were used as pump rollers. These were connected to a 6-mm (0.25-in.) aluminum plate fabricated in the research shop. Fabricated connectors were used to join

the rollers to the plate. Drawings of these are shown in Figure A-7 and A-8. The rollers were made more stable by connecting the end plates with four 5/16-inch metal rods evenly spaced around the drive shaft. These rods also ran through a bushing designed to give more surface area to connect to the drive shaft. The bushing was a piece of 64-mm (2.5-in.) diameter aluminum round stock 38 mm (1.5 in.) thick with holes bored for the drive shaft and the support shafts. Drawings of the shaft adapter are shown in Figure A-9.

A 150-cm (59-in.) long 19-mm (0.75-in.) diameter drive shaft ran through the entire assemblage. Pillow block bearings were located at both ends and in the middle of the shaft. These bearings connected the pump to a plywood and angle iron frame using plastic spacers to align the pump and shaft. These spacers also served as blocks to prevent the compression plate from turning with the shaft. Drawings of the spacers are shown in Figure A-10. Figure A-11 shows the pump assemblage.

The pump was connected to a Dayton single-phase 0.37 kW electric motor providing 30 revolutions per minute. The shaft was connected with couplings so that the motor could easily be detached for transport. Figure 4 on page 26 is a photograph of the pump without the motor attached. Recall that the sole purpose of the pump was to serve as a check valve for the air flow system, and that it simply injected the water into the air line. The air provided the transport for the water and sediment.

Runoff Redistribution System

Once the water had been transported from the bottom of the first box to the top of the second box, it had to be redistributed. The first step in this process was to remove

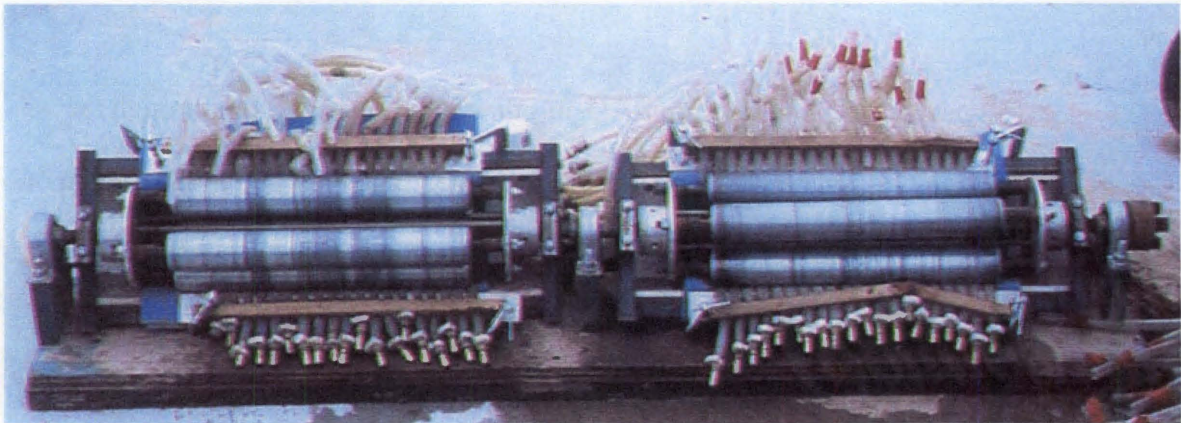


Figure 4. Pump with tubing and y-type connectors.

remove the excess energy from the system. A 61-cm (2-ft) long piece of 1/2-inch Schedule 40 IPS PVC pipe was used to vent each line. The tubing was connected to a hose barb, which had been driven into the PVC pipe 23 cm (9 in.) from the bottom. The air and water would shoot into the pipe, then the air was vented out the open top of the pipe and the water flowed down the pipe and through a slot in the capped lower end. A photograph of the pipe is shown in Figure A-12.

The pipes were placed into chutes on a 33-cm (13-in.) long sheet-metal slope. The slope was divided into 2.5-cm (1-in.) segments by sheet metal tabs riveted to the slope and sealed with silicone. This slope, which is shown in a drawing in Figure A-13, was roughened by gluing a thin layer of sand to the sheet-metal. The sheet-metal slope and the pipes were attached to a wooden frame to give support and hold the pipes in place. This frame was connected to the soil box with a hinge and to the slope stand with wood screws. The slope that redistributed the water, shown in Figure 5 on the next page, was adjustable so that the velocity of the water could be controlled to match the velocity of the runoff as it comes off of the first box. This slope was not adjusted during testing, because the exact runoff velocities were not important for the purposes of testing the system.

Site Used for Comparison

Visual observation was used to determine if the designed system was simulating combined sheet and rill erosion. The box plots were observed during and after testing to note where runoff occurred and when rilling began. In addition to this, photographs were taken at a construction site to determine where rilling occurred under natural rainfall



Figure 5. Runoff redistribution device.

conditions on a continuous slope. The site used for comparison needed to be at least as long as the combined length of the box plots, which would be 6.7 m (22 ft). The slope would also need to have a steepness of roughly 50% to match the box plot tests. An ideal field site would be free from debris, and a record would be kept of the rainfall at the site. A site meeting all the criteria was not located, but a site was located that met the two most important criteria of slope length and steepness. This site was located at a construction zone on the University of Tennessee, Knoxville campus. While the exact rainfall was unknown and there was rock on the soil surface, the site had approximately 50% slope and was just over 10 m (33ft) in length. The slope was divided into 3 segments for photography. Each segment was 3.4 m (11 ft) in length. The top section of the slope corresponded to the first box in the laboratory tests. The middle section of the slope corresponded to the second box in the laboratory tests. The bottom section of the slope represented what should have occurred in a third box, had it been included.

CHAPTER 4

RESULTS AND DISCUSSION

Observation of Experimental Setup

The box plots were observed during and after rainfall simulation to determine where runoff was occurring and where rill formation began. Plate 1 is a CD containing video taken prior to, during, and after one run of testing. Observations were also made of the components to determine if there were any problems with the system.

In both Test1 and Test 2 rills formed in the lower third of the first box, which would be approximately 2.5 meters (8 ft) down from the top of the slope. Channels occurred throughout the second box. Figure 6 shows both boxes and the channel development in each.



Figure 6. Both boxes during final test run.

Not only did channel development occur throughout the second box, but the channels formed in the second box began in almost the same location as those in the first box. Figure 7 (page 33) shows a channel of runoff dropping in the collection device, and Figure 8 (page 34) shows where the water is redistributed onto the second box.

There were a few problems that occurred during testing. In the first test, the soil slumped against the screen at the bottom of the first box, bowing it out. This made it easier for sediment to clog the screen, and it caused the channels to shift over 25 to 50 mm (1-2 in.) before dropping into the collection device. This problem was solved by reinforcing the screen before beginning the second set of tests. In the second test, there was some settling of the soil at the very end of the first box due to insufficient compaction. This was not a major problem, but it did cause the channels to shift sideways up to 50 mm (2 in.) before falling into the collection device.

In both tests, there was a slight problem with soil and water intermittently spouting from the top of a few of the air vent pipes. This was due to flow rates in those channels. The opening in the bottom of the vent pipe was not large enough to allow the water to drain fast enough. This problem was remedied by enlarging the drain opening for these pipes.

Another problem was that the runoff redistribution device did not align tightly to the surface of the soil. This created a slight indentation in the soil where the runoff exited the redistribution device. This may have removed some of the energy from the runoff.

The final problem was an edge effect. There was a barrier effect on the sides of the boxes, where runoff concentrated along the sheet metal placed on the boxes to divert splash. This formed some artificial channels along the sides of the boxes.

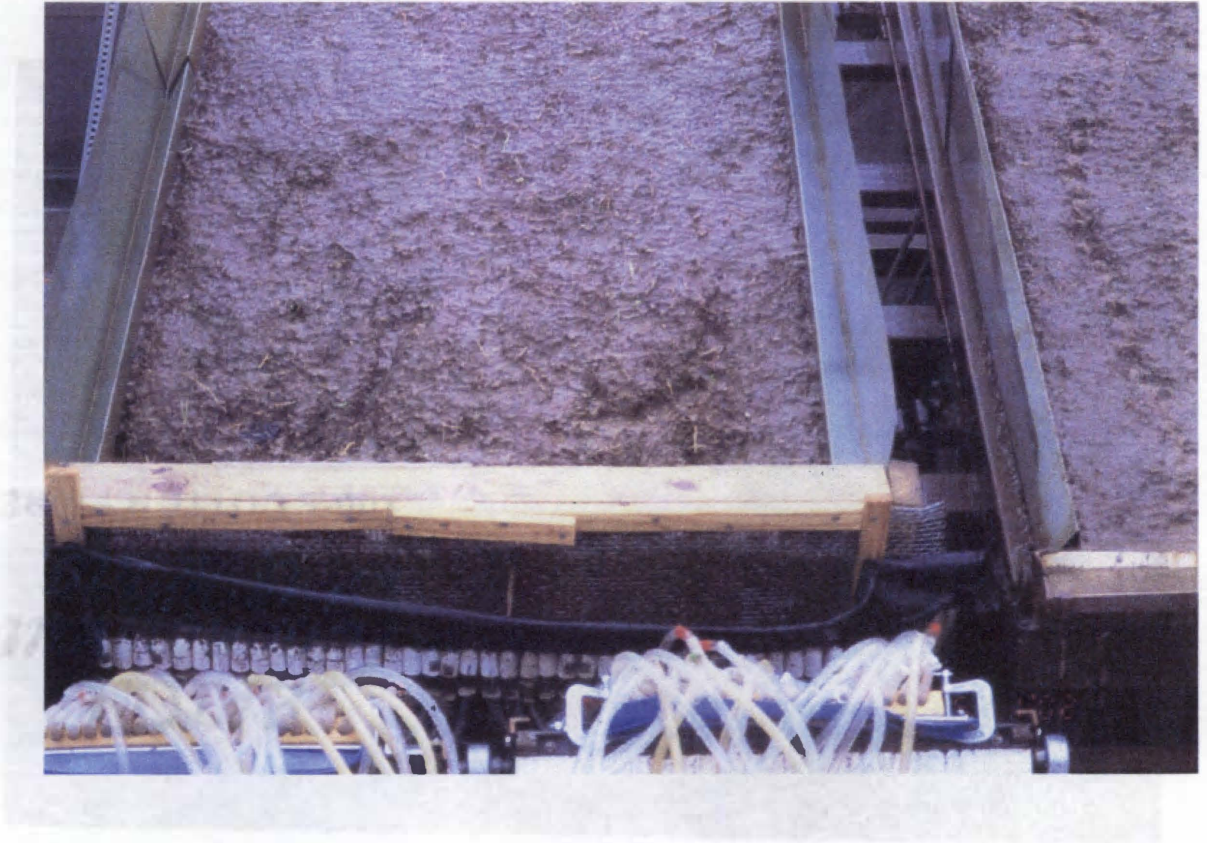


Figure 7. Photograph of bottom of first box.



Figure 8. Photograph of top of second box.

Despite these minor difficulties, the experimental system did appear to simulate sheet and rill erosion. The majority of the criteria for success set forth in the objectives were met. The channels did begin forming in the end of the first box. Channels forming in one box continued at roughly the same location in the second box, though there was some slight sideways shift before collection occurred. The channels were shallow, narrow, and did migrate upward through headcut erosion. The channels also cut downward into the soil and were roughly parallel. While the box plot system met the criteria set for success, it would be beneficial to observe a field site and compare the laboratory system to the field.

Observation of Field Site

The field site was photographed to determine how rill erosion appears under natural rainfall conditions on a continuous slope. Channels began about 2.5 m (8 ft) from the top of the hill. There were parallel channels down to about 6.5 m (22 ft) from the top of the slope, and in the section of the slope below about 6.5 m (22 ft) the rills began to form networks. The channels were narrow at the top of the hill. They began to widen just above the 10-m (33-ft) mark, where they had cut down to a less erodible layer. Figure 9, on page 36, shows the entire hillslope. The top flag is located 3.4 m (11 ft) from the top of the hill, the middle flag at 6.7 m (22 ft), and the bottom flag at 10 m (33 ft). These lengths correspond to the length of the box plots.



Figure 9. Photograph of entire slope field site.

Comparison of Experimental Setup with Field Site

The experimental system appeared to mimic the conditions found in the field. Rill development began in the lower third of the first box, which is approximately at the same location as in the field. Figure 10, on page 38, is a photograph of the first box, and in Figure 11, on page 39, the area from the top of the hill to the flag is the same location on the hill slope. In both the box plot system and the field, the rills began about 2.5 meters (8 ft) from the top of the slope. Rills in this area in were narrow and shallow in both the laboratory and field setting.

The area on the hillside from 3.4 to 6.7 m (11-22 ft) was similar to the second box of the experimental setup. Rilling occurred throughout this area, and the rills were parallel. In both locations there were more rills and they were slightly deeper than those found in the upper section of the slope. Figure 12, on page 40, shows the second box, and the area between the two flags in Figure 13, on page 41, represents the equivalent area on the hillside.

Comparison of the box plots to the field site shows that the box plots have erosion conditions that are very similar to those that are found with natural rainfall on a continuous slope. This indicates that the experimental design simulates sheet and rill erosion.



Figure 10. Photograph of first box after testing.



Figure 11. Photograph of hillside equivalent to first box.



Figure 12. Photograph of second box after testing.



Figure 13. Photograph of hillside equivalent to second box.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Visual observation of the hillside under natural conditions and the box plots indicate that the experimental setup simulates rill erosion. There are some difficulties with the experimental design. These include the fact that the mesh occasionally clogs with sediment, causing the runoff to shift sideways before moving into a channel in the collection device. There is an indentation in the soil surface where the water drops off the redistribution device. This is a problem because energy is removed from the runoff water when it ponds momentarily in this area. Another problem is that there is significant edge effect on the sides of the boxes. The next section lists recommendations for improving the system. Despite the minor problems with the system, it does meet the majority of the criteria set forth in the objectives of this research.

The runoff collection system meets its criteria. It divides the runoff area into small sections, allows collection to occur without ponding of the runoff, and minimizes the opportunity for sediment to settle out of the water.

The runoff delivery system meets most of its criteria. It can transport the runoff from the bottom of one box to the top of the next box, handle the multiple channels coming from the collection device, and function with some channels filled and other empty. It is also much less expensive than other available pumping systems. The only criteria not met is the ability to handle all of the runoff volume from the box if it were concentrated in a single channel, and this can be easily remedied by using a faster pump motor.

The runoff redistribution system fulfills its criteria as well. It can apply water to the second box at approximately the same velocity it had at the bottom of the first box. It applies the water at the same location along the width that it was collected from the first box. It prevents the sediment from settling when the transportation energy is removed.

In addition to meeting the criteria for each of the components, the system also met the criteria for success set in the objectives. The channels began forming by the end of the first box. The channels forming in one box continued in roughly the same location in the next box. There was some small shifting in the channels just before entering the collection device, but this is easily remedied. The channels were shallow, narrow, and migrated upward through headcut erosion. The channels cut down into the soil, and were roughly parallel. They did not reach a less erodible layer, and there was insufficient slope length or time for networks to form. The system appears to achieve the overall objective of simulating sheet and rill erosion using multiple box plots and a rainfall simulator.

Recommendations for Improvement

Each of the three components of the system could be improved. The runoff collection device could be improved in the following ways:

1. Extending the collection device into the soil box, perhaps with metal tabs.

This would prevent the channels from turning just before leaving the box. Figure 14 on page 45 illustrates this change.

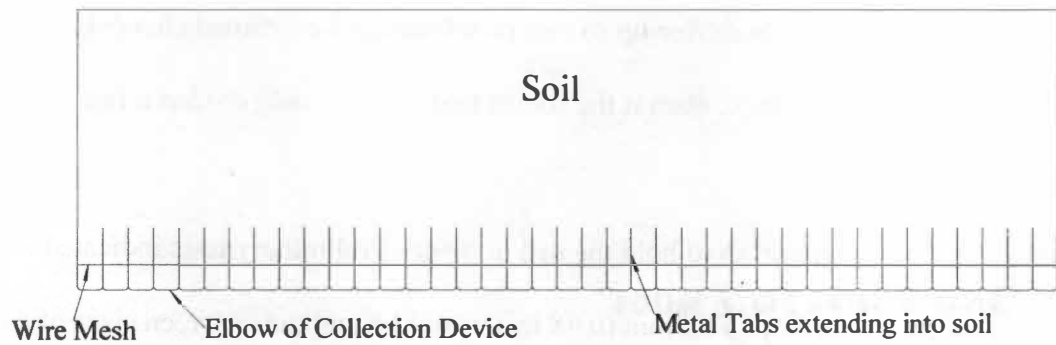
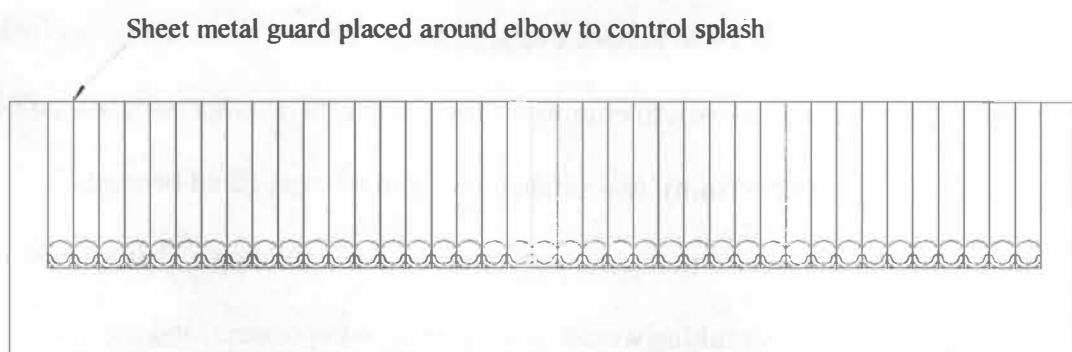


Figure 14. First improvement for collection device (top view).

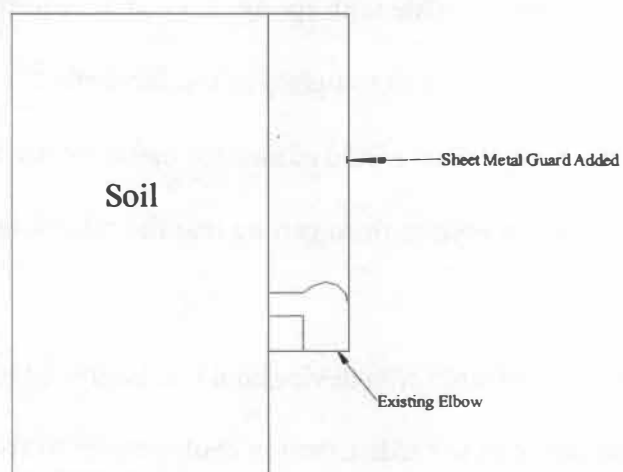
2. Inserting dividers between the elbows that are the height of the box and a splashguard around the device. Figure 15 on page 47 illustrates this change, which would help keep the runoff in the correct channel. It would eliminate the possibility that a rapidly flowing channel would shoot out over the collection device. This would also extend the collection device up so that runoff enters a contained channel as soon as it leaves the box, even if the soil in that area has only eroded a few millimeters.
3. Using a slightly larger mesh to hold the soil in place. Preliminary tests indicated that, for this soil, a screen size of 9.7mm (0.38 in.) would be optimal. Screen sizes of 6.4 mm (0.25 in.) and 12.7 mm (0.5 in.) were tested, and were found to be much too small and much too big, respectively. The screen selected for the test had an opening of 8 mm (0.32 in.) and was the size closest to 9.7 mm (0.38 in.) available. This screen had a minimal amount of clogging, but it did clog occasionally and had to be watched closely. The slight larger opening of 9.7 mm (0.38 in.) should eliminate this problem. This size screen might need to be custom made and therefore would be expensive. Another option for solving this problem would be to use a woven screen with large openings and to force the top sideways to convert the squares into parallelograms, thereby decreasing the effective size of the openings.

The runoff transport device could be improved in the following ways:

1. Trying a slightly smaller inside diameter of hose for the air lines. This would reduce



Front View



Side View

Figure 15. Second improvement for collection device.

the required airflow while still transporting the water effectively. Reducing the tubing size to 4.8 mm (0.19 in.) inside diameter would reduce the air flow required to $1\text{ m}^3/\text{min}$ ($20\text{ ft}^3/\text{min}$). This would eliminate the need to rent a compressor that could provide $2.3\text{ m}^3/\text{min}$ ($80\text{ ft}^3/\text{min}$); two smaller size compressors could be used. Tests would need to be performed to make sure that the line did not clog. Using a 6.32 mm (0.25-in.) inside diameter tubing would strain 3 small compressors, and anything larger than that requires a high volume air compressor.

2. Using a faster motor for the pump. The one selected didn't have a high enough rpm to transport the runoff if it all concentrated in one or two channels, and it wouldn't be able to handle the runoff from the bottom of a second box.
3. Converting the pump rollers to a spring loaded system. This system would compress the rollers against the plate with springs instead of requiring the complex compression plate structure to be locked so tightly to the drive shaft.
4. Covering the pump. This would reduce the metal oxidation caused by rainfall. It would also prevent objects from getting into the rollers, making the pump safer.

The runoff redistribution device could be improved in the following manner:

1. Moving the outlet of the redistribution chutes closer to the soil surface. This should eliminate the line in the soil where the water drops off the device.
2. Making the slope of the redistribution chute more easily adjustable. This would allow for convenient changes in slope to match runoff velocities.
3. Covering the device so that the runoff from rain landing on it would not reach the box.

This would ensure that only the rainfall that actually falls on the plot area contributes to the runoff volume.

The final recommendation applies to the box plot design. To eliminate edge effects, the outside 5 cm (2 in.) of each long side of the box should be dropped out of the system instead of being carried to the next box. This would be done by determining the minimum plot width desired and adding 10 cm (4 in.) to the width of each box in the sequence. If the minimum plot width is 1 m (39 in.) for a three-box system, the bottom box would be 1.1 m (43 in.) wide, the next box up would be 1.2 m (47 in.) wide, and the top box would be 1.3 m (51 in.) wide. Figure 16 on page 48 illustrates how this would work. Discarding the outer two inches of each box will eliminate the excess runoff that has accumulated along the barrier at the edge of the box, creating unnatural rills.

These suggestions should improve the setup. Even without the changes the design meets the basic requirements for transporting water containing sediment from the bottom of one box to the top of another while maintaining channels.

Recommendations for Future Research

In the immediate future, this system needs to be tested further. Visual observation indicates that the setup simulates rill erosion, but a more stringent test comparing the laboratory system to field data should be conducted. One means of comparison might be rill cross-sectional area. Another means might be using a 3 or 4 box system and looking at rill network development.

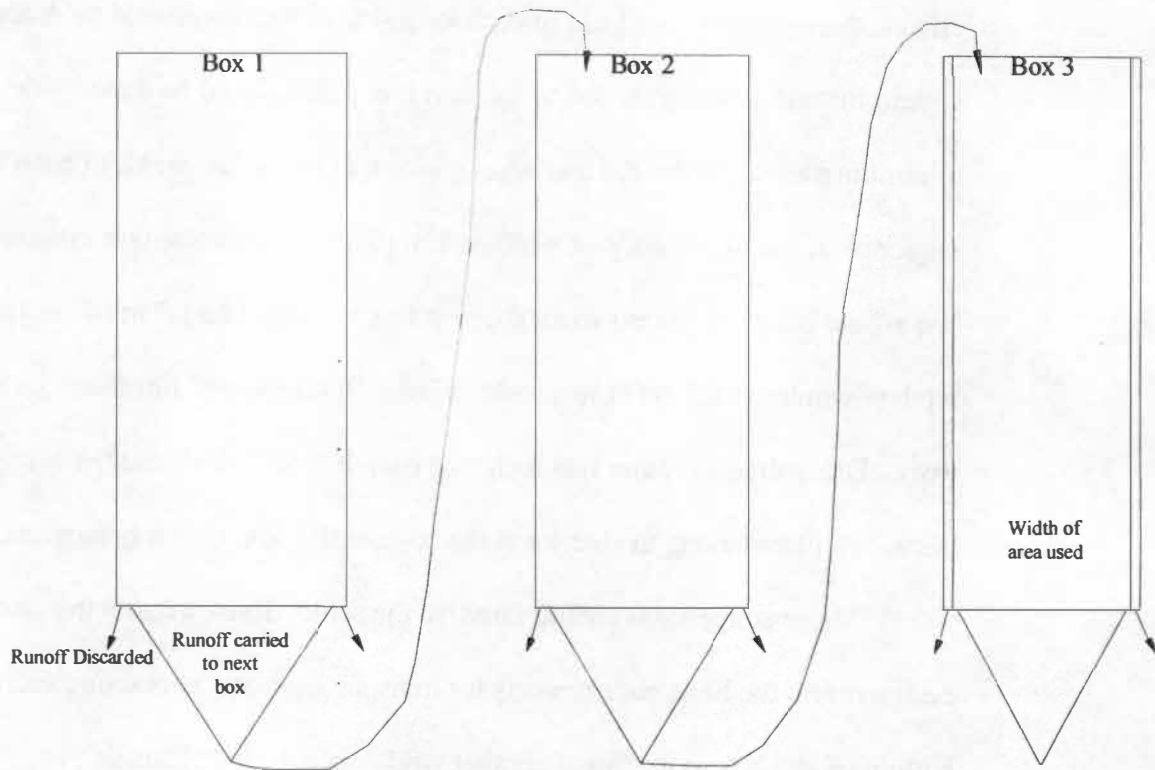


Figure 16. Removal of edge effect.

If further testing confirms that the rills formed in the box plot setup simulate field conditions accurately, then the opportunities for future research using this system are vast. This system could be used for any research where several repetitions are required. It could be used to test cover material for the soil surface, as well as types of incorporated residue. It could also allow researchers to study erosion mechanics in a new way. Past laboratory research, while providing control of conditions, has not been able to look at sheet and rill erosion occurring at the same time because of slope length limitations. This setup is unique because it simulates both interill and rill erosion on an entire slope length.

LIST OF REFERENCES

LIST OF REFERENCES

- Alberts, E. E., W.C. Moldenhauer, and G. R. Foster. 1980. Soil aggregates and primary particles transported in rill and interrill flow. *Soil Sci. Soc. Am. J.* 44:590-595.
- Buchanan, J. R. 2000. The Use of Wood Chips to Control Soil Erosion on Construction Sites. Unpublished Doctoral dissertation, Knoxville: The University of Tennessee.
- Ellison, W. D. and O. T. Ellison. 1947. Soil erosion studies- Part VI Soil detachment by surface flow. *Agr. Eng.* 28:402-405.
- Foster, G. R. 1982. Modeling the erosion process. In *Hydrologic Modeling of Small Watersheds*, eds. C. T. Haan et al., 297-323. St. Joseph, MI: ASAE.
- Foster, G. R., L. F. Huggins, and L. D. Meyer. 1984. A laboratory study of rill hydraulics: I. Velocity relationships. *Trans. ASAE* 27(3):790-796.
- Foster, G. R., C. B. Johnson, and W. C. Moldenhauer. 1982a. Critical slope lengths for unanchored cornstalk and wheat straw residue. *Trans. ASAE* 25(4):935-939,947.
- Foster, G. R., C. B. Johnson, and W. C. Moldenhauer. 1982b. Hydraulics of failure of anchored cornstalk and wheat straw residue. *Trans. ASAE* 25(4):940-947.
- Foster, G. R. and L. D. Meyer. 1977. Soil erosion and sedimentation by water- An overview. In *Proc. National Symposium on Soil Erosion and Sedimentation by Water*, 1-13. Chicago, IL: ASAE.
- Franti, T. G., G. R. Foster, and E. J. Monke. 1996. Modeling the effects of incorporated residue on rill erosion: Part II Experimental results and model validation. *Trans. ASAE* 39(2):535-550.
- Gabbard, D. S., C. Huang, L. D. Norton, and G. C. Steinhardt. 1998. Landscape position, surface hydraulic gradients and erosion processes. *Earth Surf. Processes and Landforms* 23:83-93.
- Govers, G. 1991. Time-dependency of runoff velocity and erosion: The effect of the initial soil moisture profile. *Earth Surf. Processes and Landforms* 16(8):713-729.
- Guy, B. T., W. T. Dickinson, and R. P. Rudra. 1987. The roles of rainfall and runoff in the sediment transport capacity of interrill flow. *Trans. ASAE* 30(5):1378-1386.
- Haan, C. T., B. J. Barfield, and J. C. Hayes. 1994. *Design Hydrology and Sedimentology for Small Catchments*. San Diego, CA: Academic Press.

- Huang, C., L. K. Wells, and L. D. Norton. 1999. Sediment transport capacity and erosion processes: Model concepts and reality. *Earth Surf. Processes and Landforms* 24(6):503-516.
- Lal, R. and W. Elliot. 1994. Erodibility and erosivity. In *Soil Erosion Research Methods*, ed. R. Lal, 181-210. Ankeny, IA: Soil and Water Conservation Society.
- Laws, J. O. and D. A. Parsons. 1943. The relationship of raindrop-size to intensity. *Trans. Amer. Geophys. Union* 24:452-460.
- Liu, B. Y., M. A. Nearing, and L. M. Risse. 1994. Slope gradient effects on soil loss for steep slopes. *Trans ASAE* 37(6):1835-1840.
- Merz, W. and R. B. Bryan. 1993. Critical conditions for rill initiation on sandy loam Brunisols: laboratory and field experiments in southern Ontario, Canada. *Geoderma* 57:357-385.
- Meyer, L. D. 1994. Rainfall simulators for soil erosion research. In *Soil Erosion Research Methods, Second Edition*, ed. R. Lal, 83-103. Ankeny, IA: Soil and Water Conservation Society.
- Meyer, L. D., G. R. Foster, and S. Nikolov. 1975. Effect of flow rate and canopy on rill erosion. *Trans. ASAE* 18(5):905-911.
- Meyer, L. D., C. B. Johnson, and G. R. Foster. 1972. Stone and woodchip mulch for erosion control on construction sites. *J. Soil & Water Conser.* 27(6):264-269.
- Meyer, L. D. and M. A. Ports. 1976. Prediction and control of urban erosion and sedimentation. In *Proc. National Symposium on Urban Hydrology, Hydraulics, and Sediment Control, July 27-29, 1976*, 323-331. Lexington: University of Kentucky.
- Meyer, L. D., W. H. Wischmeier, and G. R. Foster. 1970. Mulch rates required for erosion control on steep slopes. *Soil Sci. Soc. Am. Proc.* 34(6):928-930.
- Mutchler, C. K., C. E. Murphree, and K. C. McGregor. 1994. Laboratory and field plots for erosion research. In *Soil Erosion Research Methods, Second Edition*, ed. R. Lal, 11-37. Ankeny, IA: Soil and Water Conservation Society.
- Nearing, M. A., L. D. Norton, D.A. Bulgakov, G. A. Larionov, L. T. West, and K.M. Donstsova. 1997. Hydraulics and erosion in eroding rills. *Water Resources Res.* 33(4):865-876.
- Nearing, M. A., J. R. Simanton, L. D. Norton, S. J. Bulygin, and J. Stone. 1999. Soil erosion by surface water flow on a stony, semiarid hillslope. *Earth Surf. Processes and Landforms* 24:677-686.

Renard, K. G., G. R. Foster, G. A. Weesies, D. K. McCool, and D. C. Yoder, coordinators. 1997. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*. USDA, Agricultural Handbook No. 703.

Schmidt, J. 1991. Impact of rainfall on sediment transport by sheetflow. In: *Erosion, Transport, and Deposition Processes*, ed. H. R. Bork, 9-17. Destedt, Germany: Catena Supplement 19.

Shainberg, I., D. Warrington, and J. M. Laflen. 1992. Soil dispersibility, rain properties, and slope interaction in rill formation and erosion. *Soil Sci. Soc. Am. J.* 56:278-283.

Shelton, C. H., R. D. von Bernuth, and S. P. Rajbhandari. 1985. A continuous-application rainfall simulator. *Trans. ASAE* 28(4):1115-1119.

Walker, P. H., J. Hutka, A. J. Moss, and P. I. A. Kinnell. 1977. Use of a versatile experimental system for soil erosion studies. *Soil Sci. Soc. Am. J.* 41:610-612.

APPENDICES

Appendix A: Photographs and Drawings of System Components

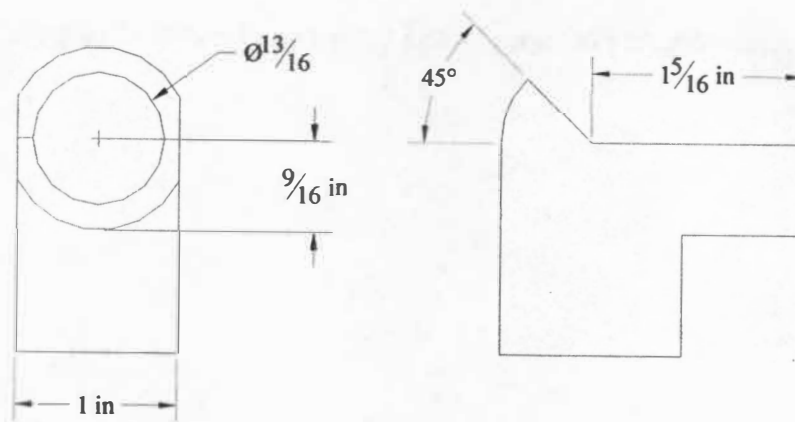


Figure A-1. Drawing of elbow cut for collection device.

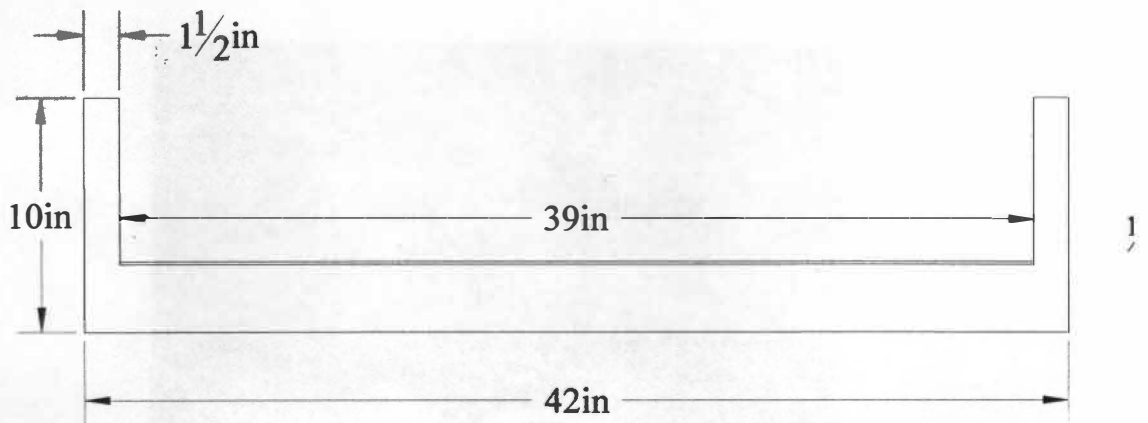
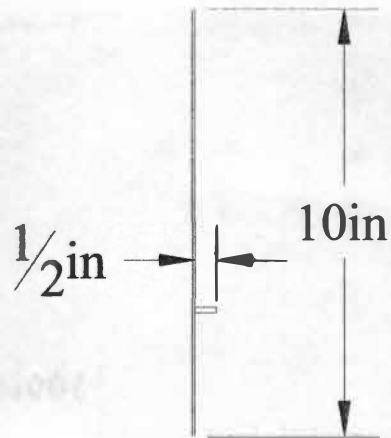


Figure A-2. Drawings of sheet metal for collection device.

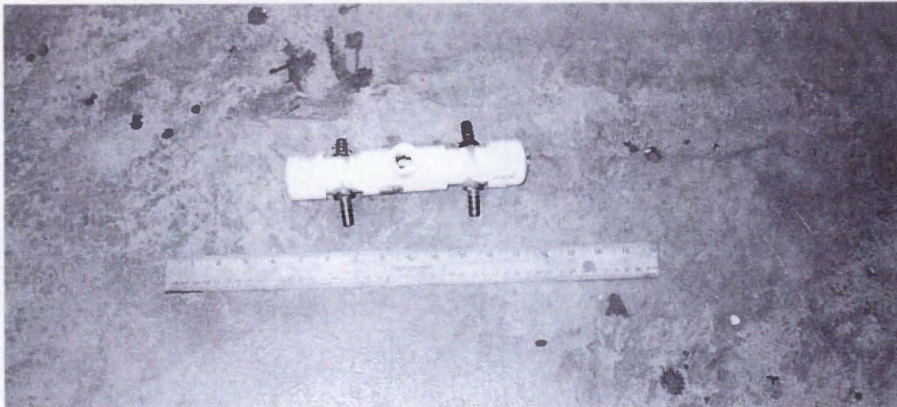


Figure A-3. First manifold.

Used to divide air flow from compressor to four lines for secondary manifold.

1 inch Manifold

1/2 Female NPT inflow connection

3/8 in hose barb outflow connections

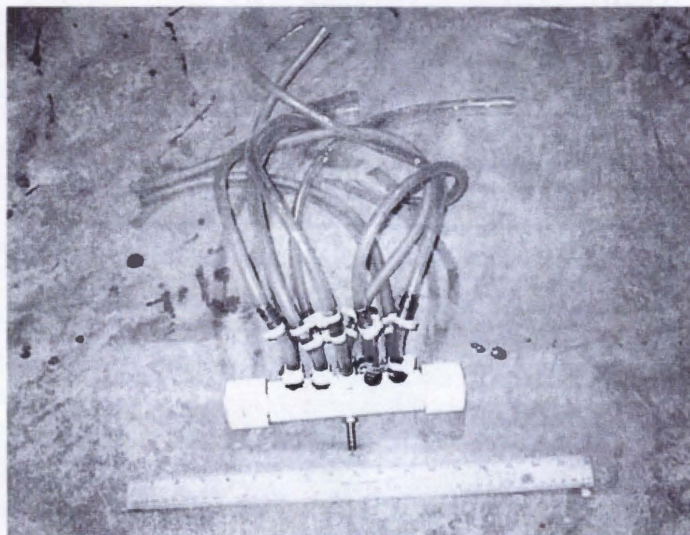


Figure A-4. Second manifold.

Used to divide lines from primary manifold into nine or ten outlets for individual runoff lines.

1.25 inch manifold

3/8 inch hose barb inflow and outflow connections

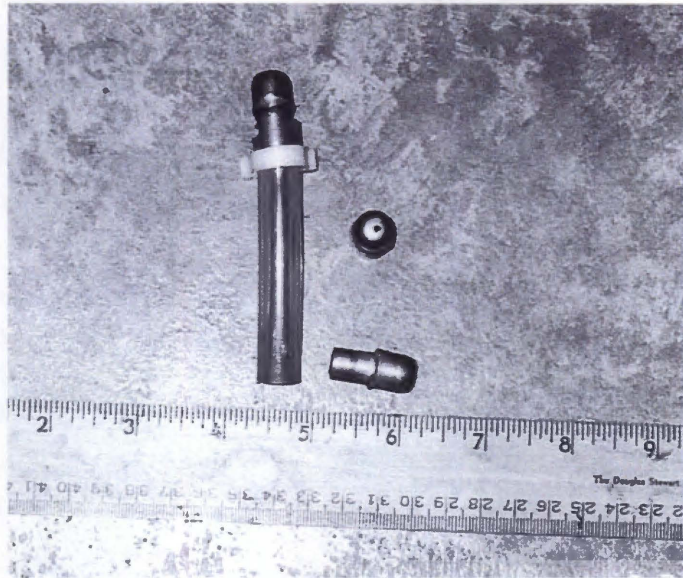
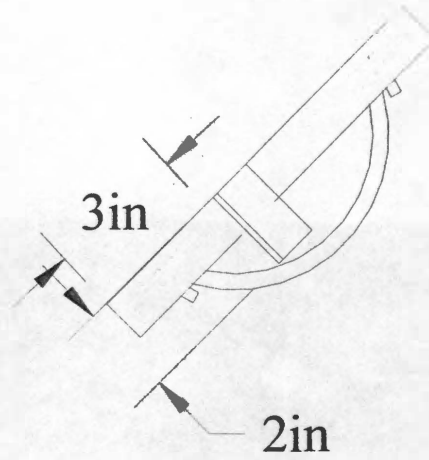
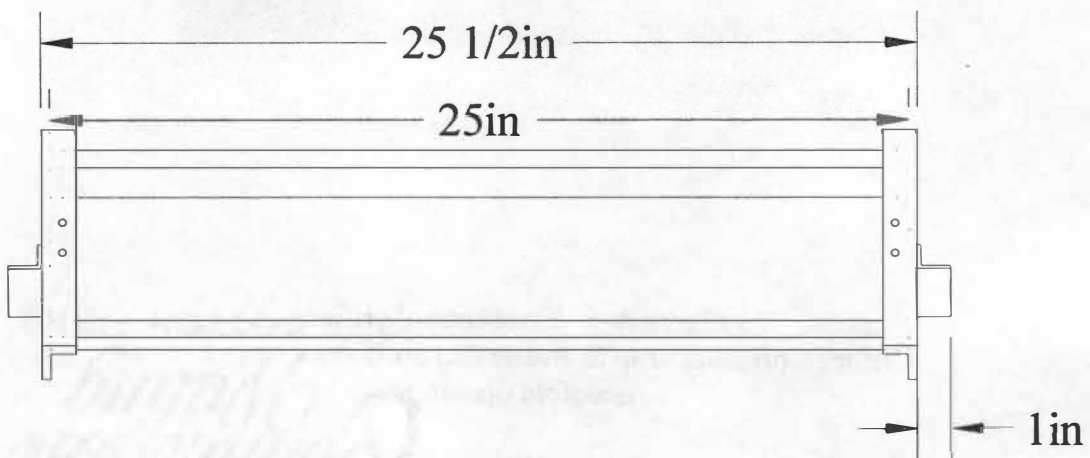


Figure A-5. Flow control orifice.
Creates a pressure drop to ensure that air flows evenly from all manifold openings.



Side View



Front View

Figure A-6. Drawings of PVC pipe and angle iron frame.
(Dashed lines represent hidden lines.)

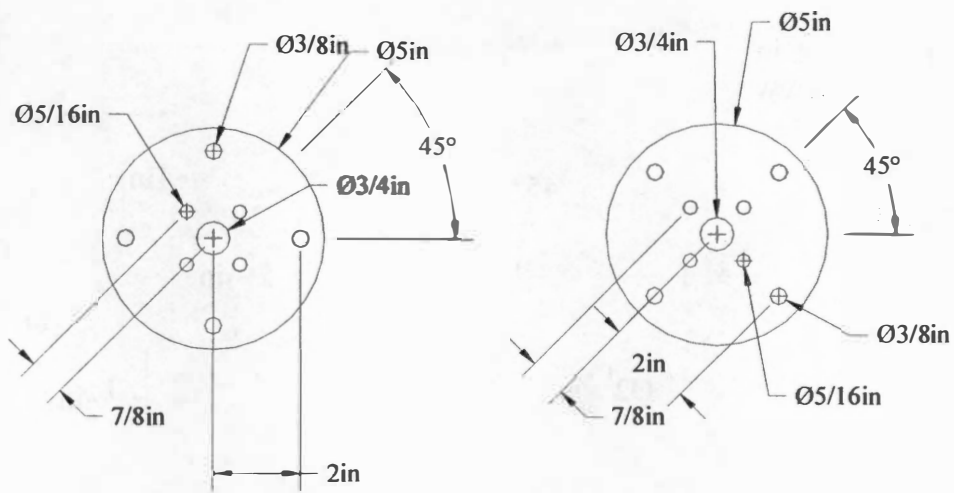


Figure A-7. End plates for peristaltic pump.

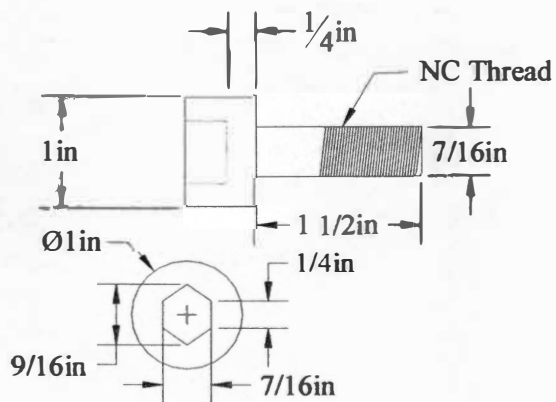


Figure A-8. Connector for rollers.
(Dashed lines represent hidden lines.)

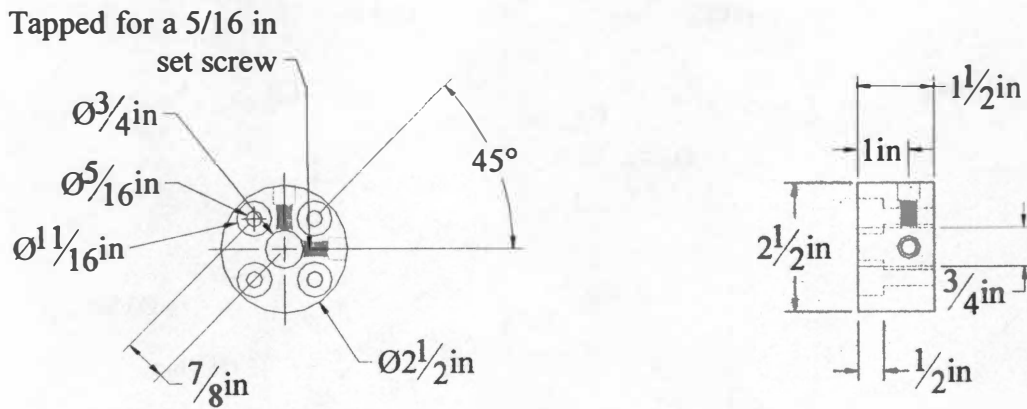


Figure A-9. Adapter for pump shaft.
(Dashed lines represent hidden lines.)

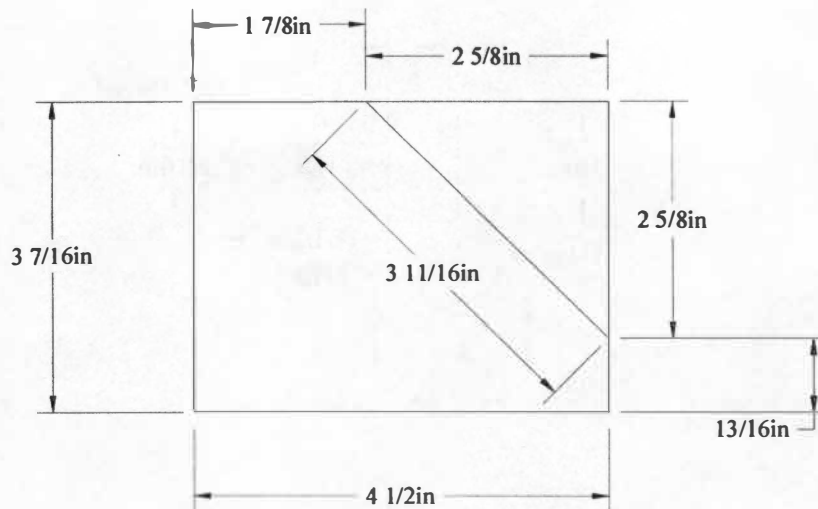


Figure A-10. Plastic spacers for pump mounting.

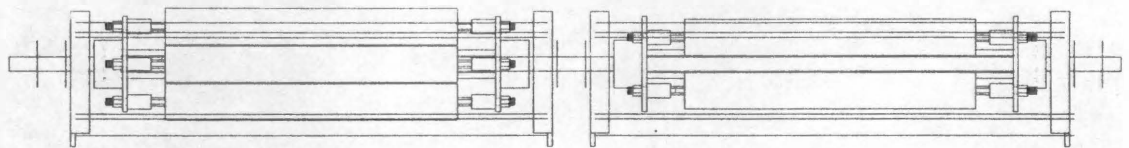
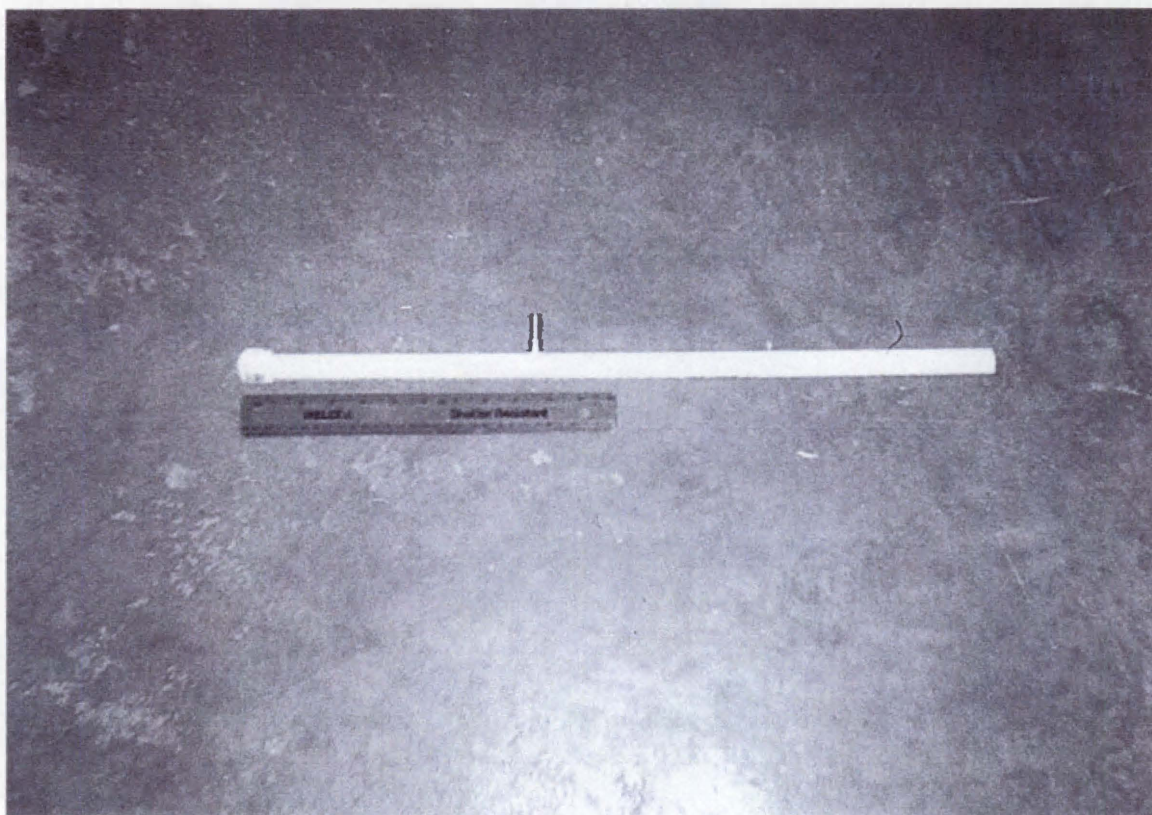


Figure A-11. Pump schematic.

Tubing was 1/2 inch outside diameter
Compression plate pulled against rollers with 2 inch long 5/16 inch bolts connected
to a piece of 3/4 inch steel square tubing cut with a 1 inch diameter hole saw
Steel pipe with 3/4 inch inside diameter and 1 inch outside diameter used as bearing



**Figure A-12. Photograph of PVC pipe air vent.
Removes excess energy from transported water.**

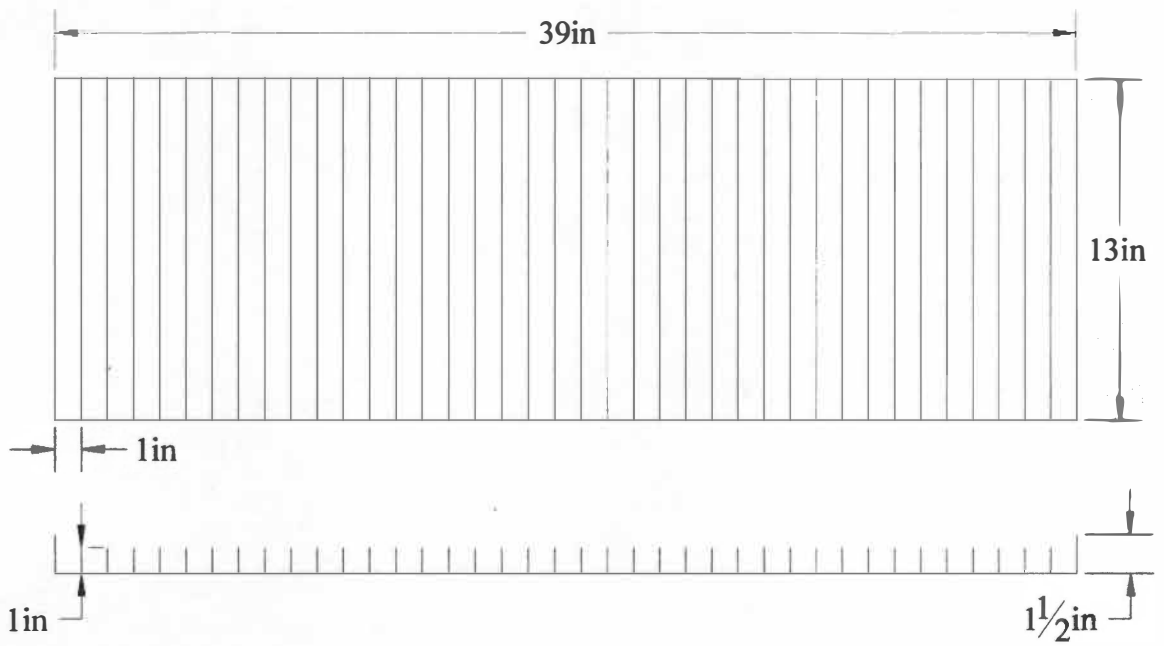
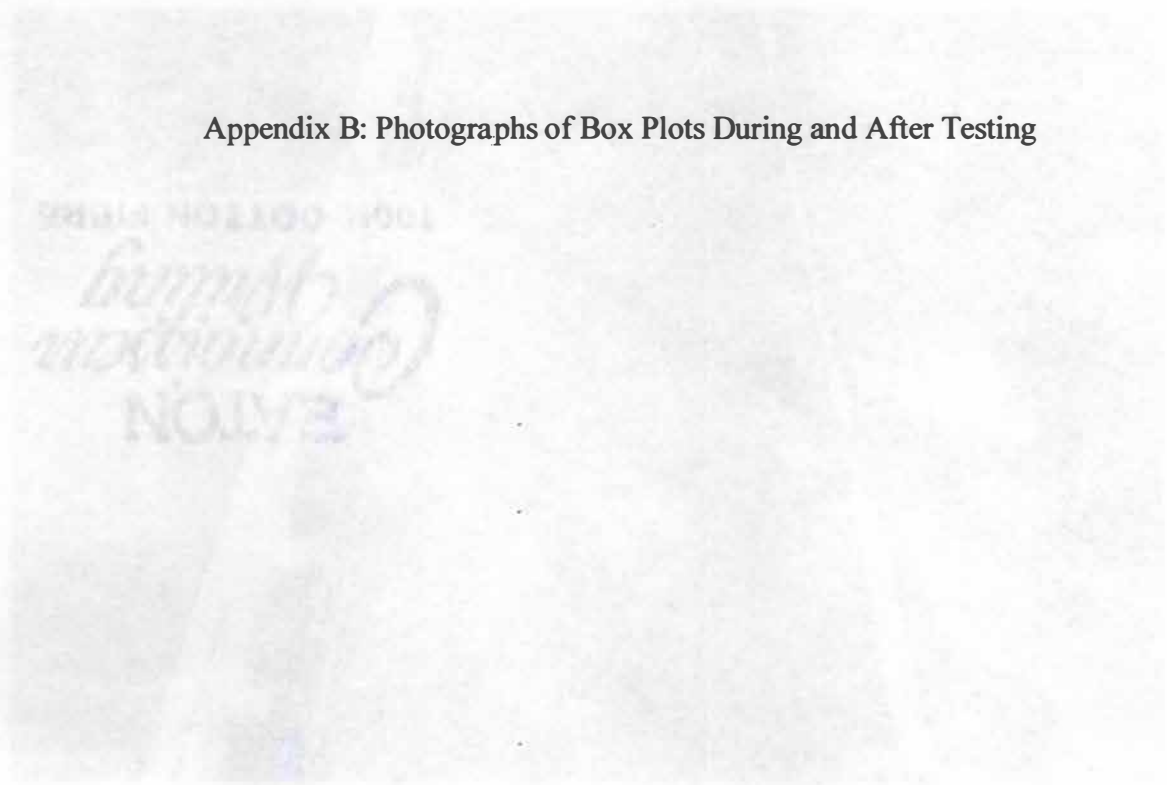


Figure A-13. Drawing of redistribution chute.

Appendix B: Photographs of Box Plots During and After Testing



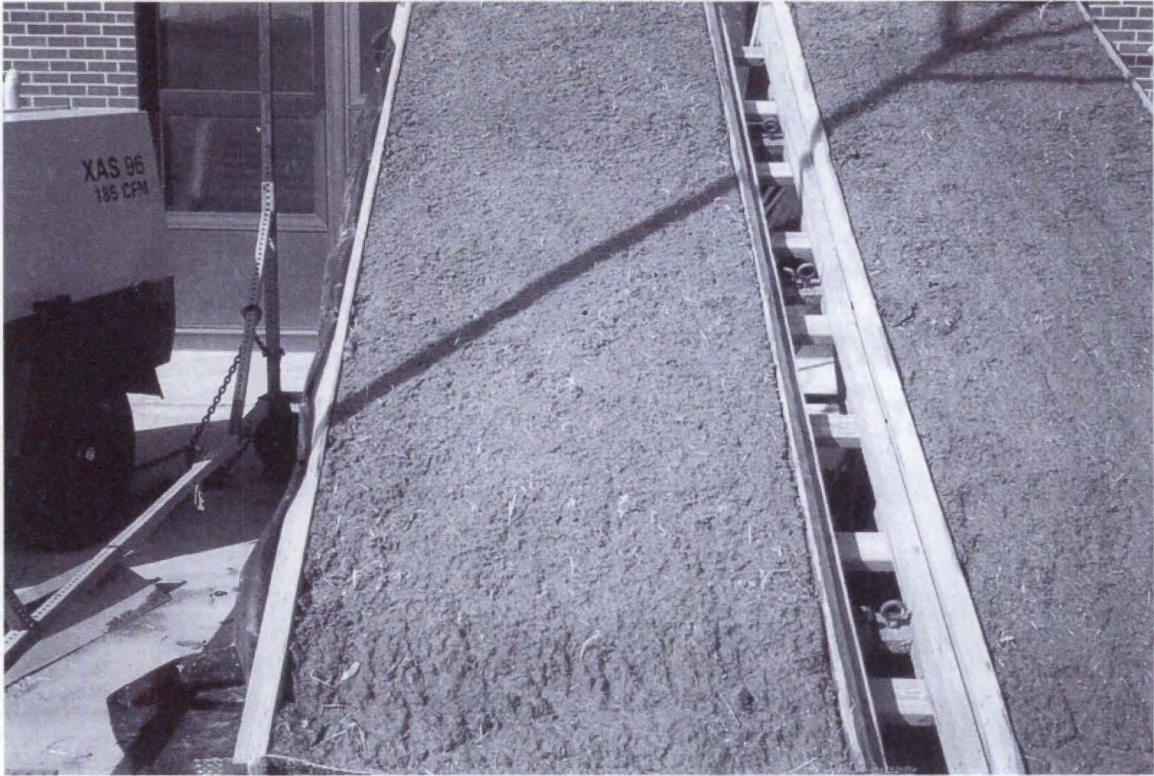


Figure B-1. Box 1 test 1 after third run.



Figure B-2. Box 2 test 1 after third run.



Figure B-3. Test 1 during fourth run.

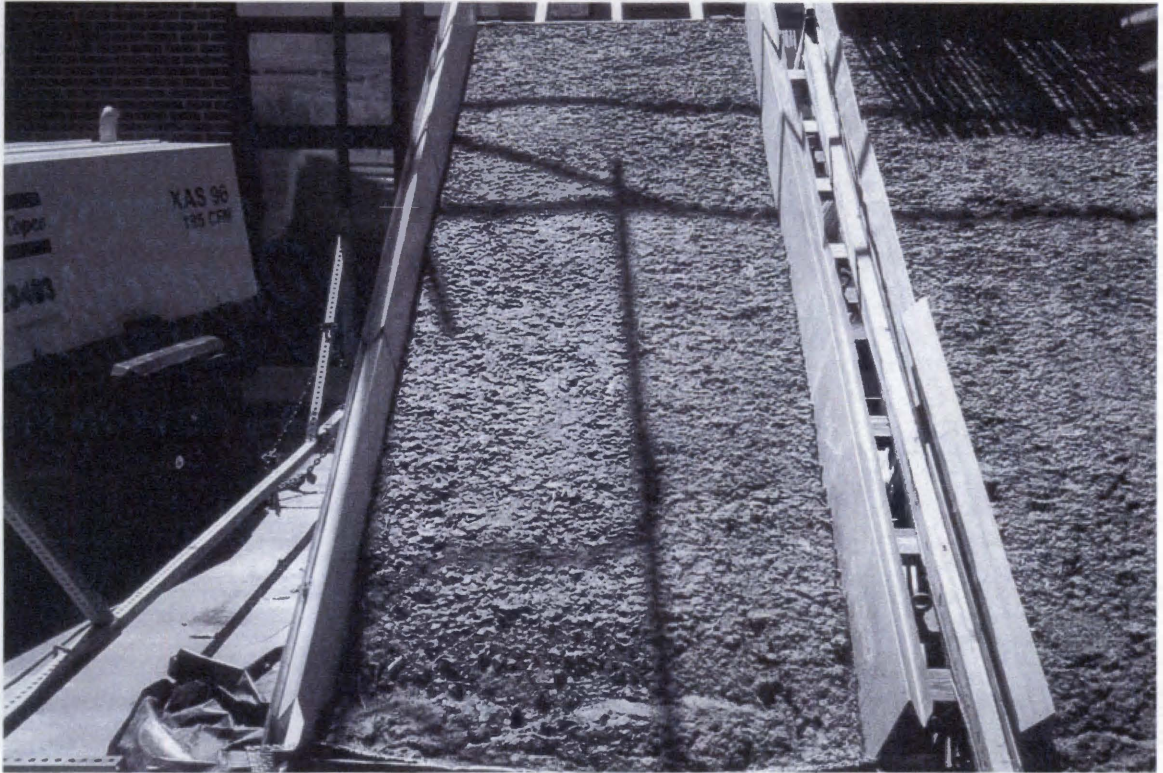


Figure B-4. Box 1 test 1 after fourth run.



Figure B-5. Box 2 test 1 after fourth run.

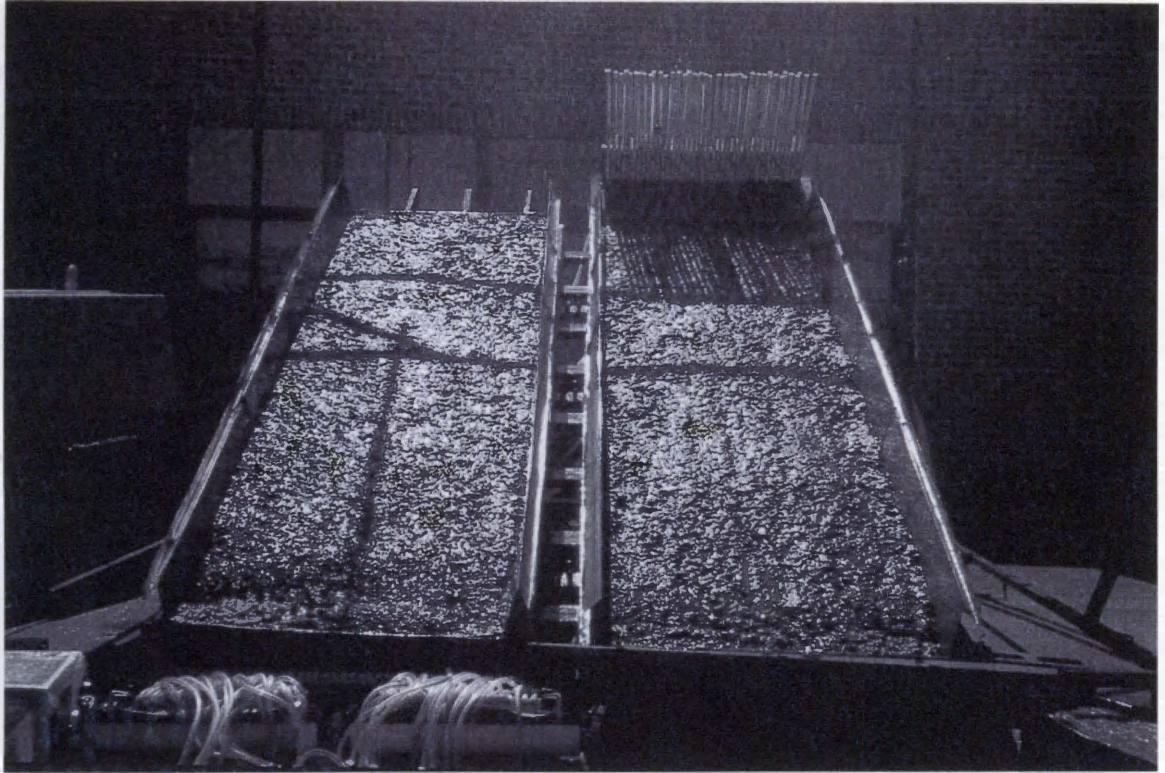


Figure B-6. Test 1 during fifth run.



Figure B-7. Box 1 test 1 after fifth run.

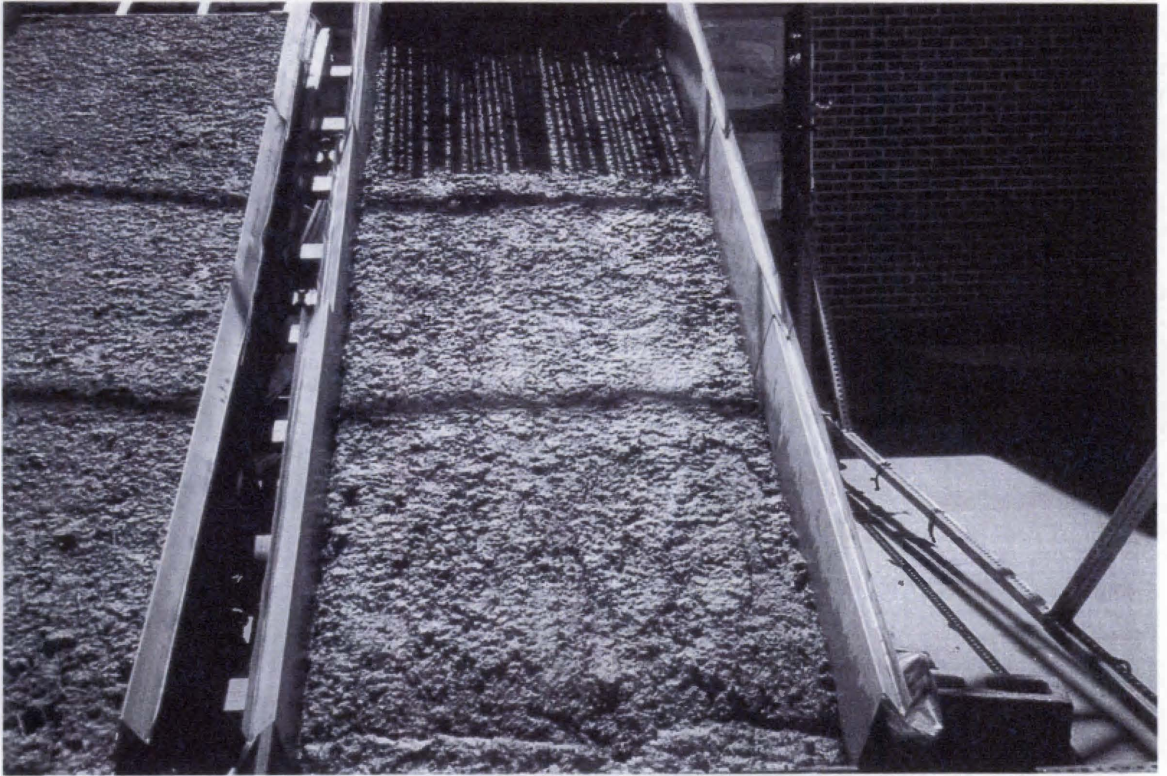


Figure B-8. Box 2 test 1 after fifth run.

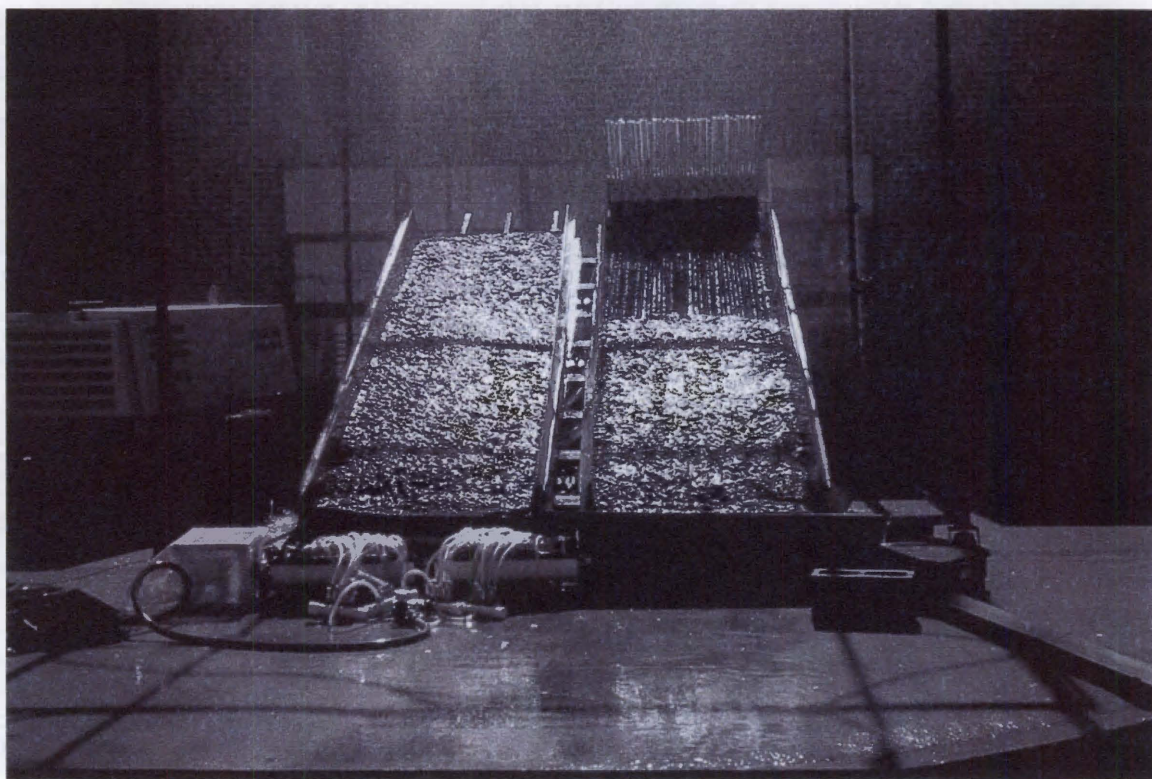


Figure B-9. Test 1 during sixth run.



Figure B-10. Box 1 test 1 after sixth run.



Figure B-11. Box 2 test 1 after sixth run.

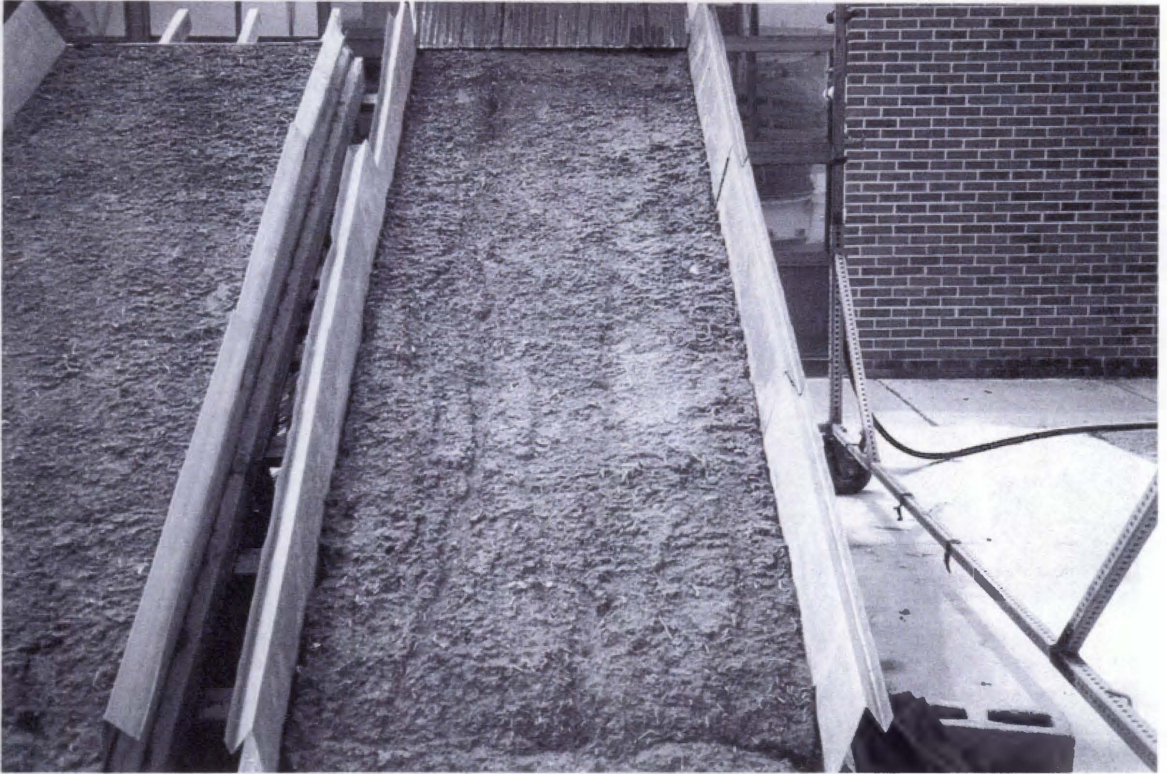


Figure B-12. Box 2 test 2 after seventh run.

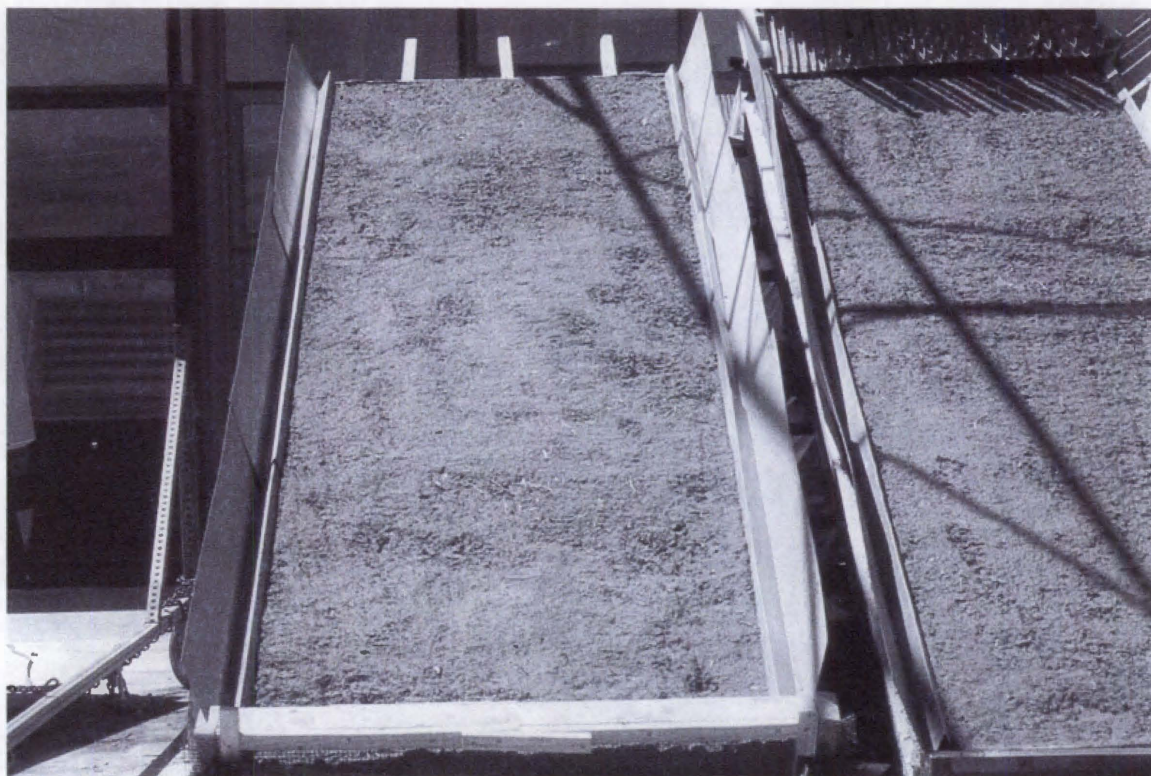


Figure B-13. Box 1 test 2 after first run.

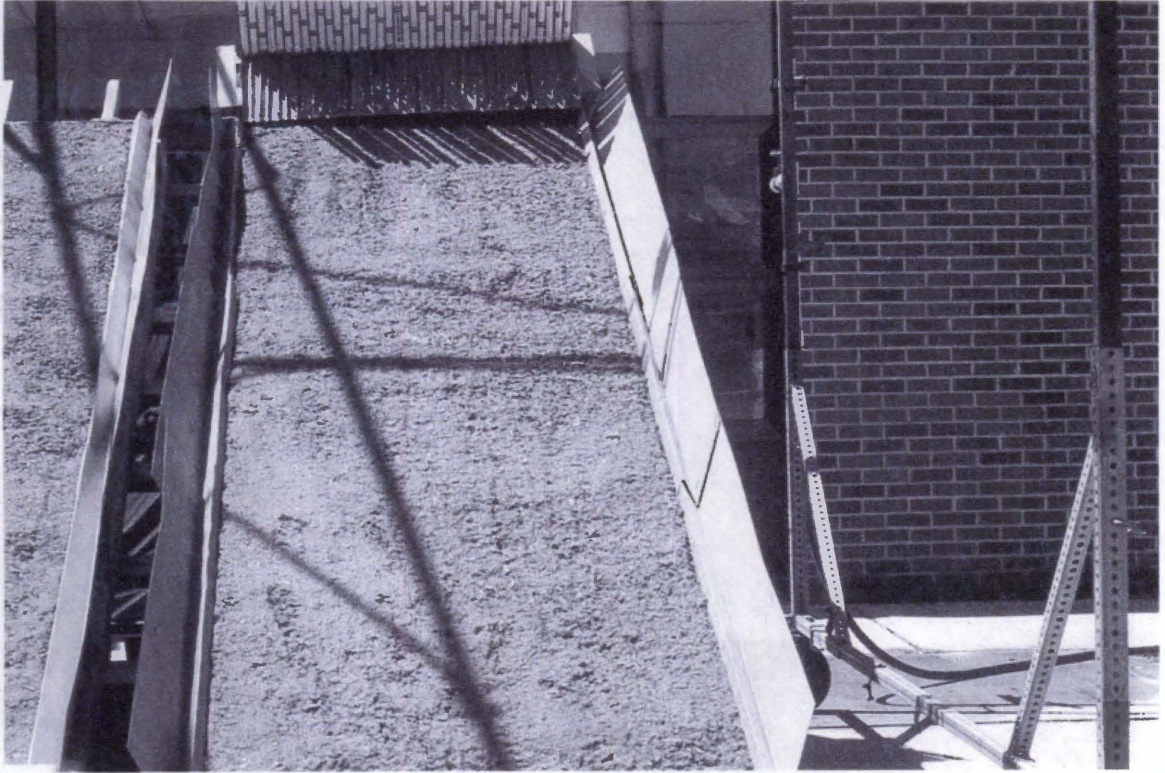


Figure B-14. Box 2 test 2 after first run.

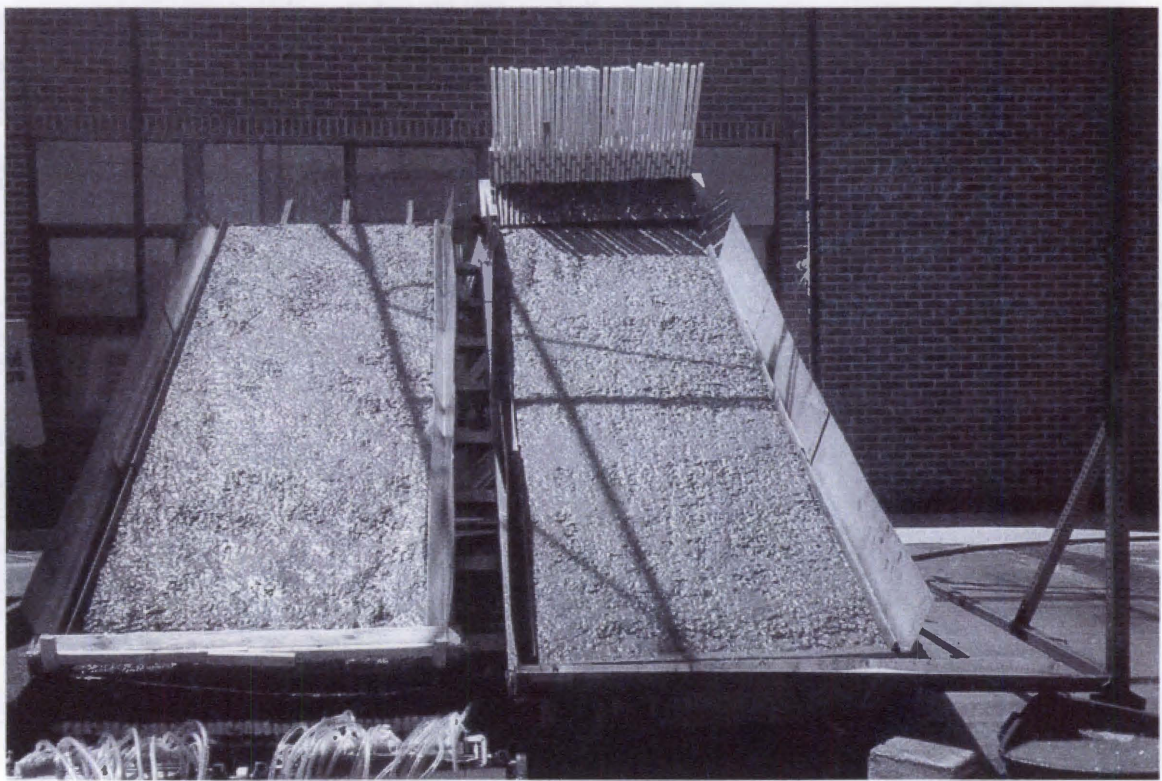


Figure B-15. Test 2 during second run.

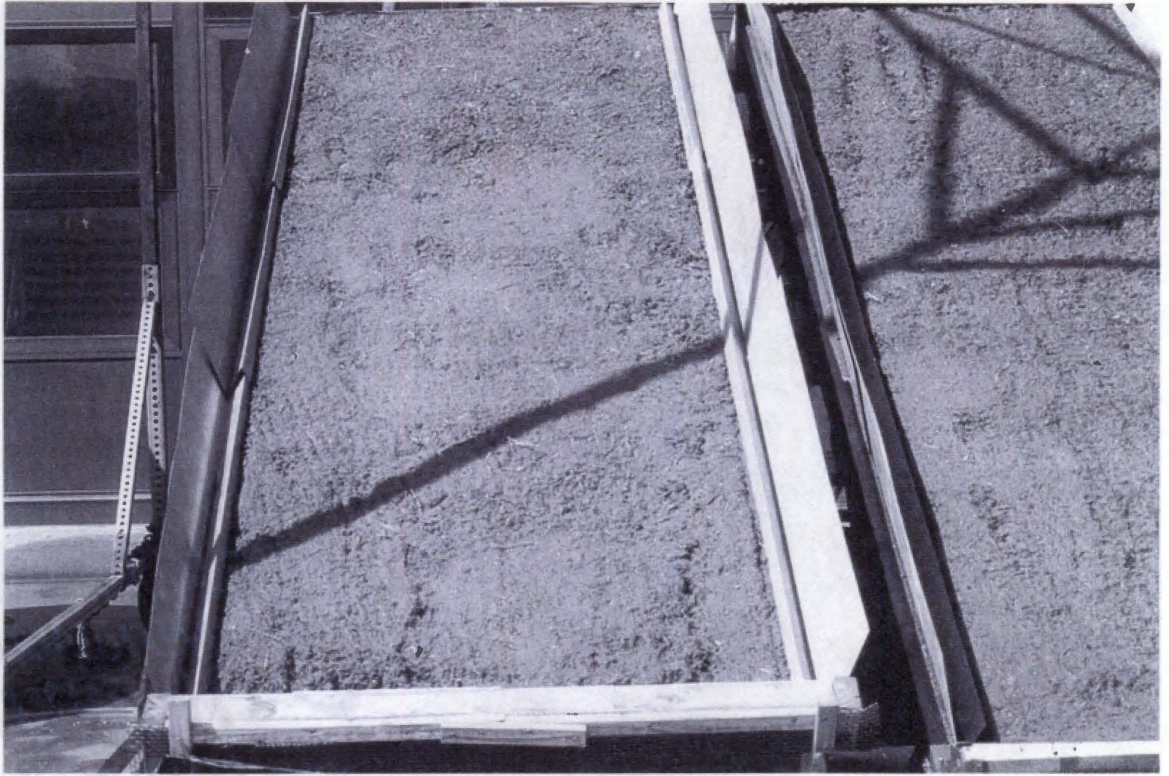


Figure B-16. Box 1 test 2 after second run.



Figure B-17. Box 2 test 2 after second run.

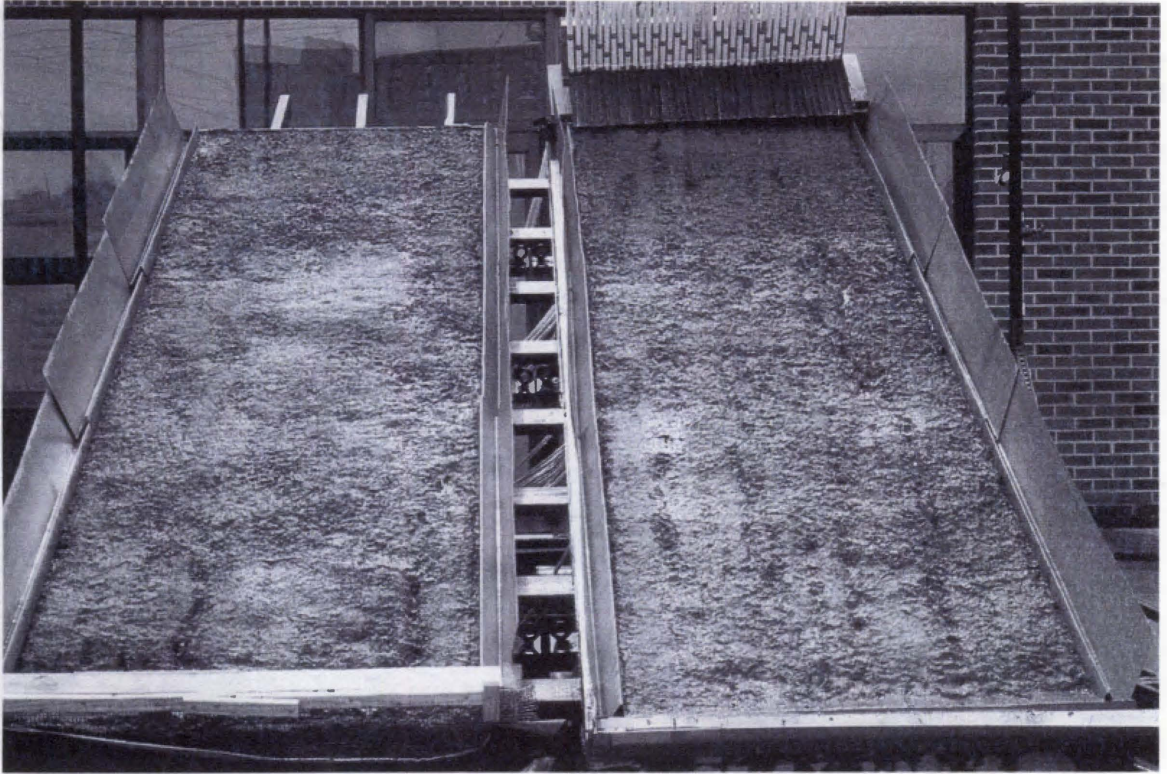


Figure B-18. Test 2 during fourth run.

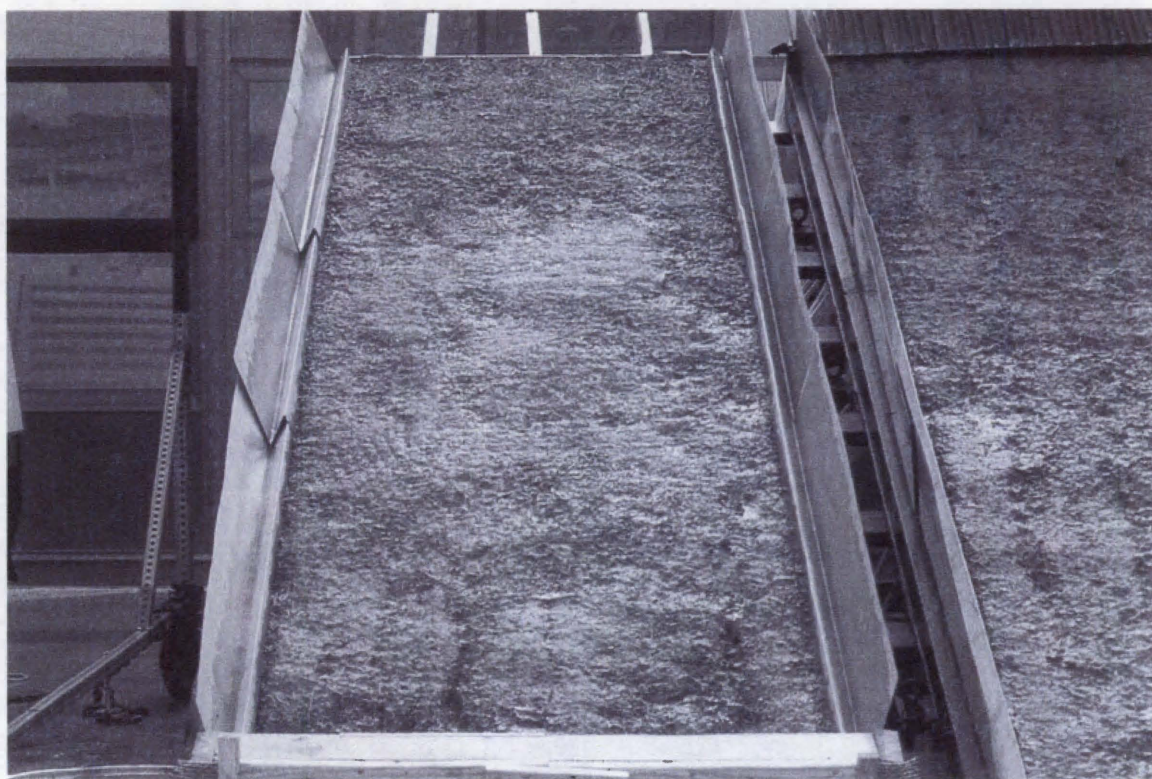


Figure B-19. Box 1 test 2 after fourth run.

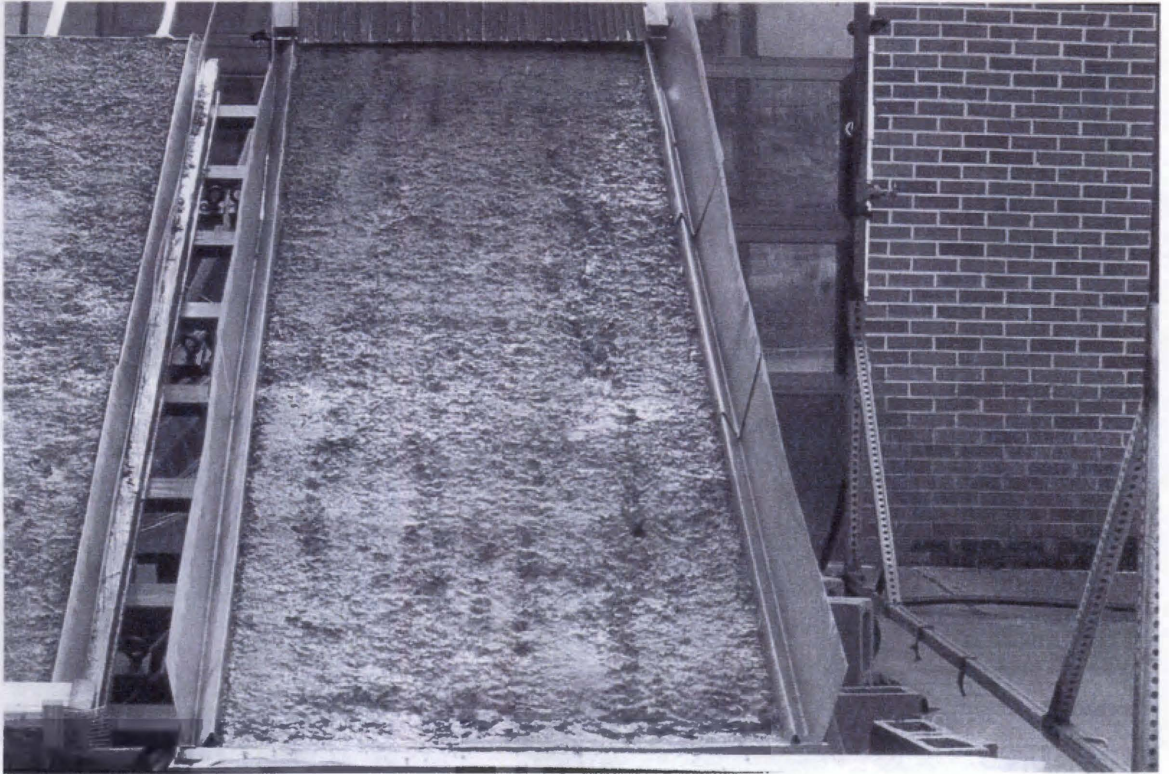


Figure B-20. Box 2 test 2 after fourth run.

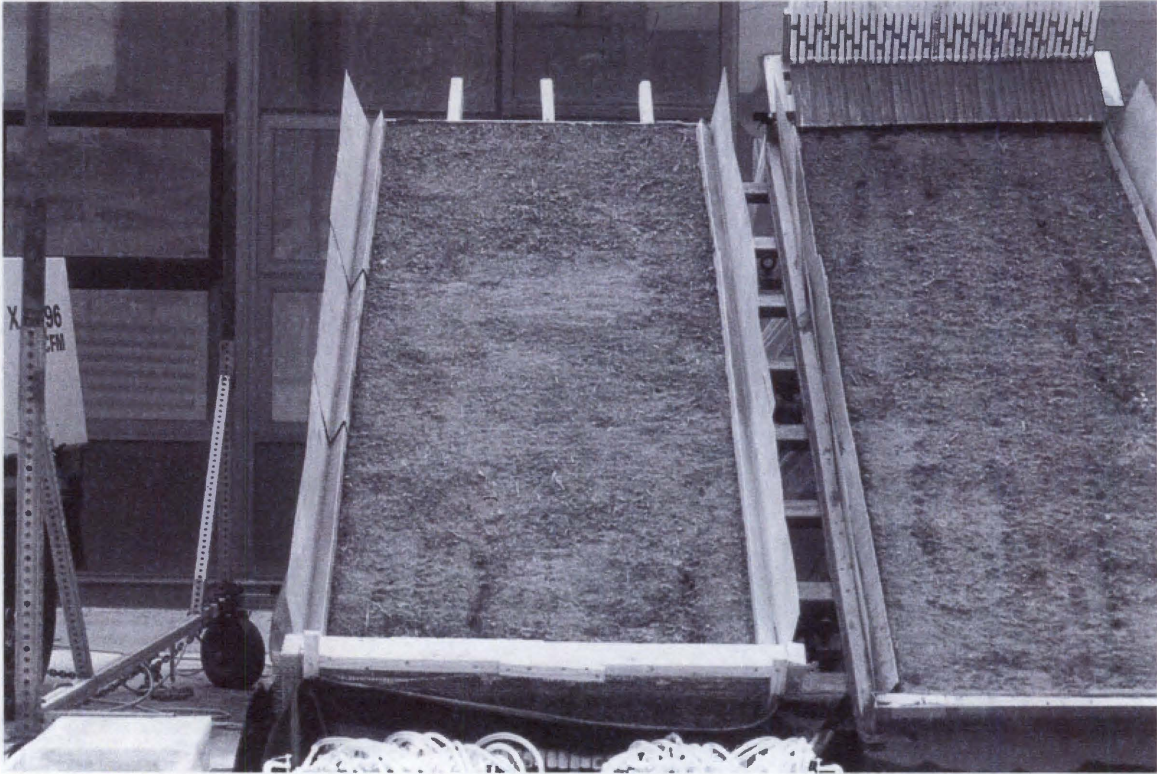


Figure B-21. Box 1 test 2 after fifth run.

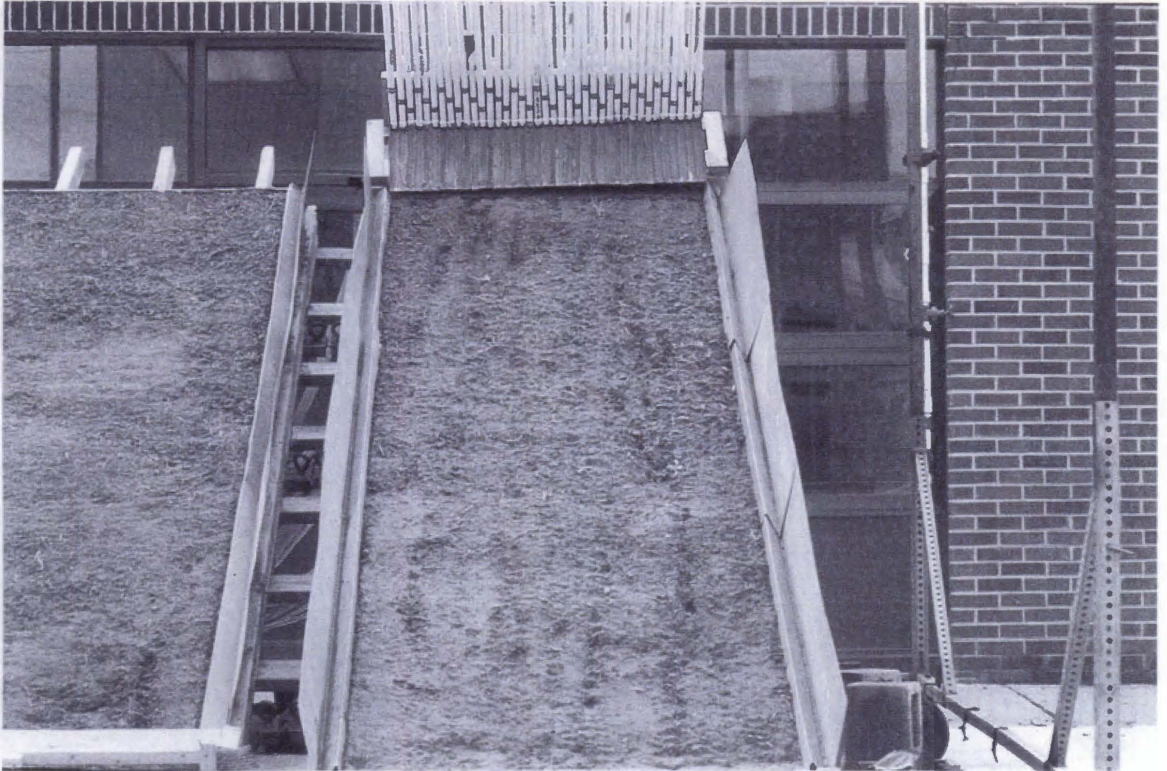


Figure B-22. Box 2 test 2 after fifth run.

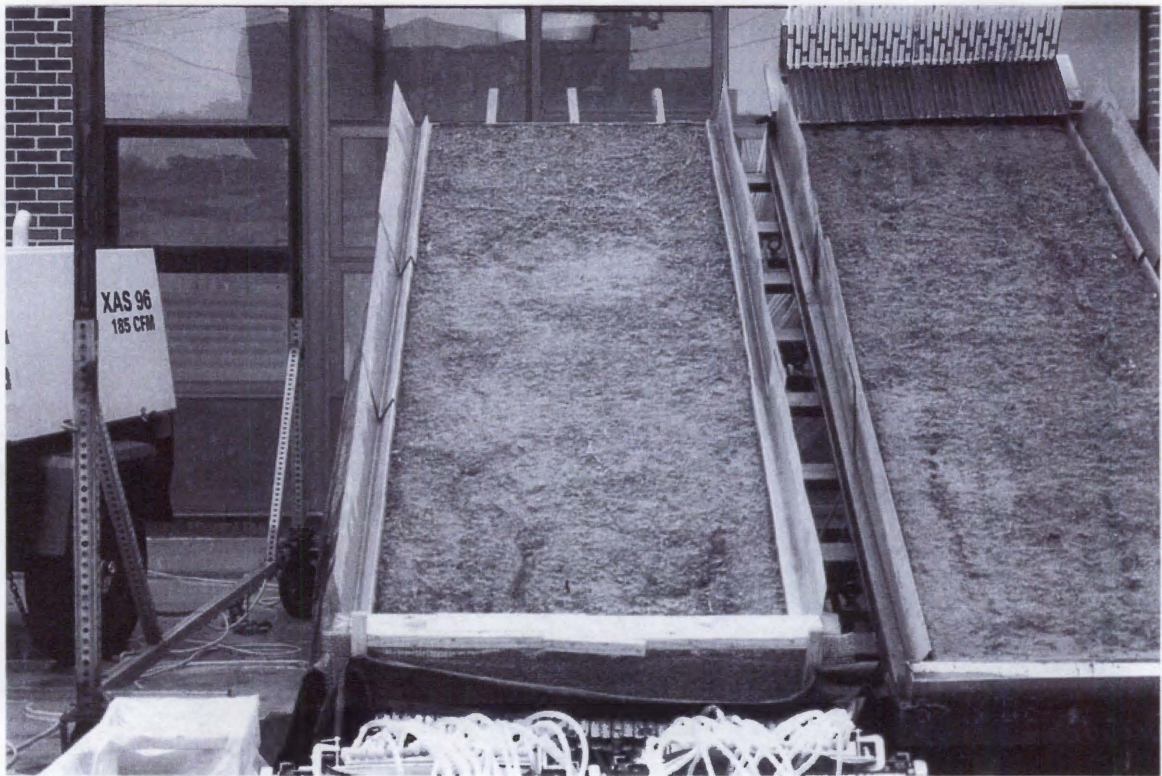


Figure B-23. Box 1 test 2 after demonstration run.



Figure B-24. Box 2 test 2 after demonstration run.

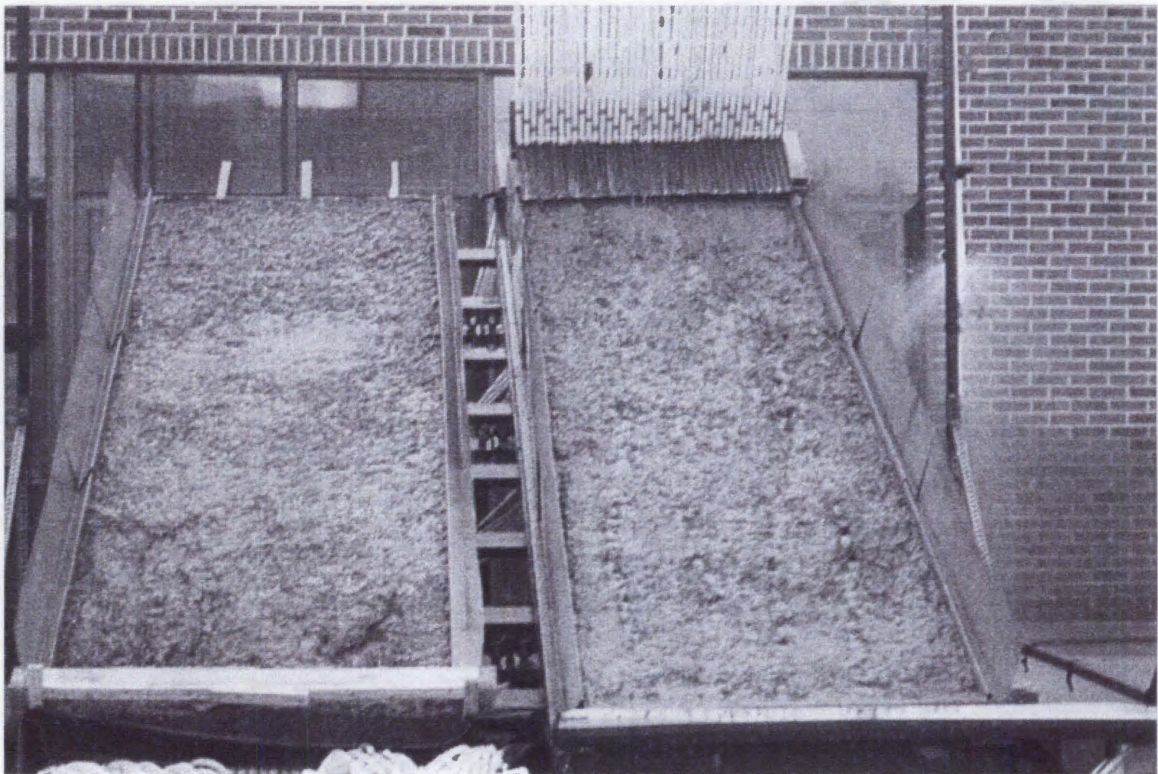


Figure B-25. Test 2 during final run.



Figure B-26. Box 1 test 2 after final run.

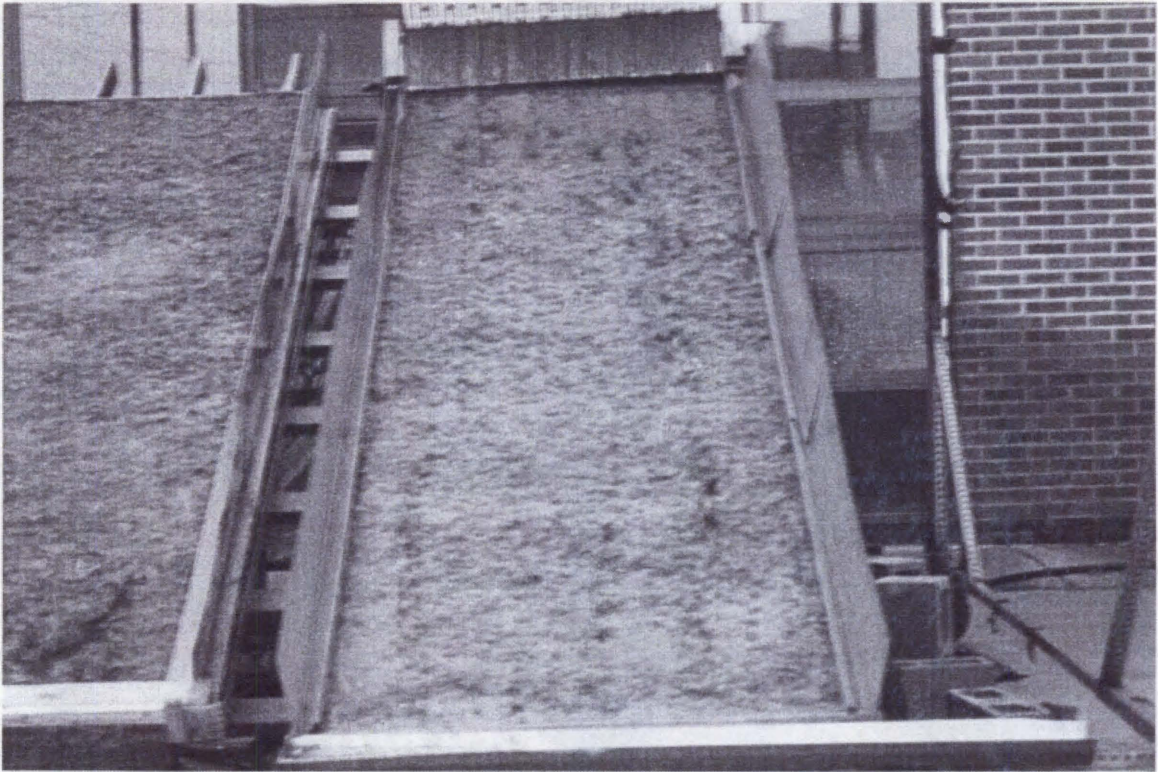


Figure B-27. Box 2 test 2 after final run.

Appendix C: Photographs of Field Site



Figure C-1. Top of hill.

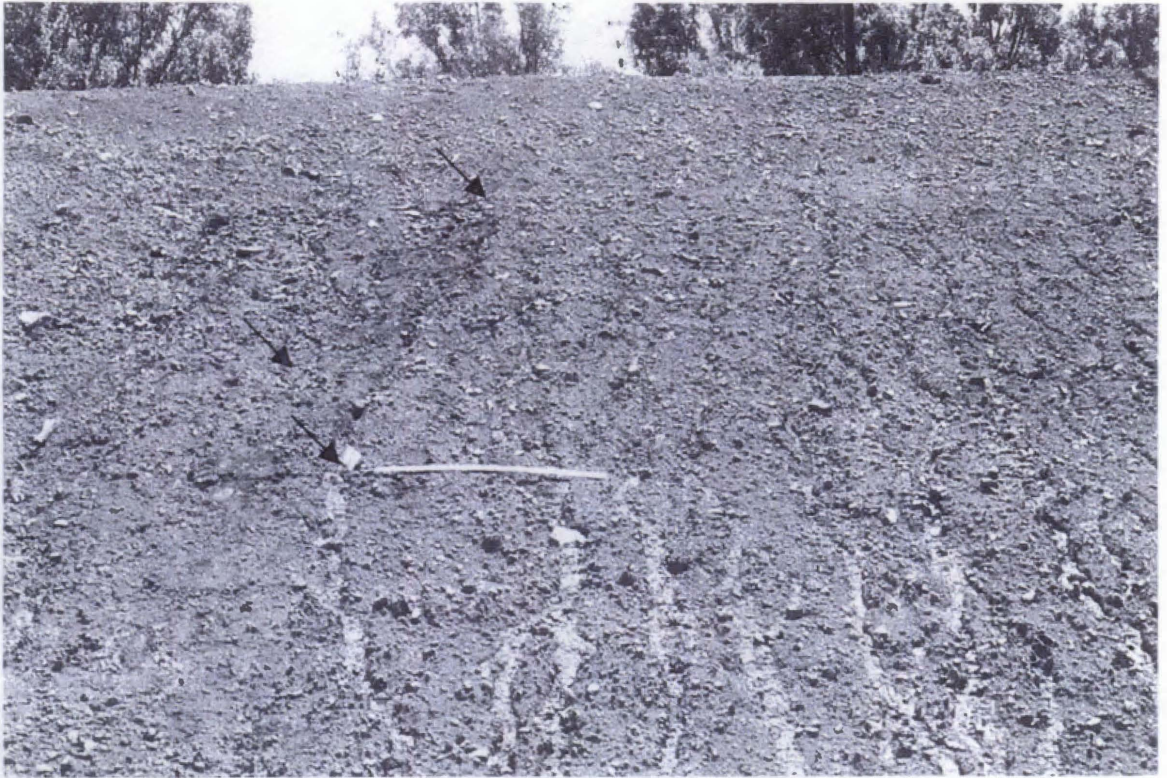


Figure C-2. Middle of hill.



Figure C-3. Entire hill.

VITA

Meredith Leigh Crosby was born in 1977 in Parsons, Tennessee. Meredith was raised on a small, beef and swine production farm in Decatur County. Meredith attended primary school in Parsons and graduated first in her class at Riverside High School in May 1995. At Riverside, Meredith was very active in the FFA Organization. She also played softball and was in the drama club.

In August 1995, Meredith began college at the University of Tennessee, Knoxville with a major in Plant Soil Science. Meredith received a Bachelors of Science in December of 1999. From September 1997 until August 2000, Meredith worked for the University of Tennessee as an undergraduate research assistant in soybean breeding and genetics. Meredith took a short leave from this position June through August 1999 to work as an intern with Knox County and the Natural Resources Conservation Service on the Knox County Soil Survey.

In August 2000, Meredith began the graduate program in Biosystems Engineering Technology. She hopes to complete her Masters by August 2002.